# Estimation of Aerosol Optical Depth using MODIS satellite data and its relation with particulate matter concentration in the mining regions

**Satyabrata Behera**

Department of Mining Engineering
**National Institute of Technology Rourkela**

# Estimation of Aerosol Optical Depth using MODIS satellite data and its relation with particulate matter concentration in the mining regions

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*by*

***Satyabrata Behera***

(Roll Number: 711MN1170)

*Under the supervision of*

***Prof. Amit Kumar Gorai***

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Department of Mining Engineering

**National Institute of Technology Rourkela**

Department of Mining Engineering

**National Institute of Technology Rourkela**

**Prof. Amit Kumar Gorai**

Assistant Professor

May 16, 2016

# Superisor's certificate

This is to certify that the work presented in this dissertation entitled "*Estimation of Aerosol Optical Depth using MODIS satellite data and its relation with particle matter concentration in the mining regions"* by "Satyabrata Behera", Roll Number 711MN1170, is a record of original research carried out by him under my supervision and guidance in partial fulfilments and requirements of the degree of B. Tech and M. Tech Dual degree in Mining Engineering. Neither this dissertation nor any part of it has been submitted for any degree or diploma to any institute or university in India or abroad.

Amit Kumar Gorai

Assistant Professor

*Dedicated to my family and friends*

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May 16, 2016
NIT Rourkela

*Satyabrata Behera*
Roll Number: 711MN1170

# Abstract

Airborne contaminants occur in the gaseous form or as aerosols. They may exist in the form of airborne dust, sprays, mists, smokes and fumes. According to occupational health study, all these forms may be important because they relate to a wide range of occupational health diseases. The atmosphere in the mines is always associated with dust, fumes and different gasses. Compare to underground coal mines, dust generation at opencast mines is too high. These days to fulfill the demand rate, there is an increasing in the number of opencast coal mines. Those release an enormous amount of dust. Drilling, blasting, loading and unloading, coal handling and transportation are the common sources of air pollution in mines. These air pollutants degraded the air quality, and they have an adverse impact on the health of people, animals and agriculture. Ground-based monitoring of particulate matter ($PM_{10}$ and $PM_{2.5}$) has been restricted to few selective sites. To overcome the problem, the present study utilised the Aerosol Optical Depth (AOD) level measured from satellite data to estimate the $PM_{2.5}$ concentration over different coal mines. Aerosol Optical Depth is the measure of aerosols distributed over the column of air from the earth surface to the atmosphere. The present study analyses Moderate Resolution Imaging Spectroradiometer (MODIS) data to estimate AOD levels. MODIS on board Terra (originally known as EOS AM-1) and Aqua (originally known as EOS PM-1) satellites are viewing the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands, or groups of wavelengths. So that annual, seasonal and diurnal variation of AOD level can be studied. Seasonal/monthly AOD variation were estimated for the year 2014-2015 over the coal mining regions of Odisha state. Diurnal AOD variations were studied during three months (April-June, 2014). The AOD levels were extracted from the AOD maps and used for regression analysis (both simple and multiple) for prediction of particulate matter ($PM_{2.5}$) dust concentrations.

The regression modelling approach predicted the development of linear, multiple regression models to estimate $PM_{2.5}$ concentration using MODIS AOD, and in-situ measured meteorological parameters. The simple regression results revealed that the regression coefficient between AOD and $PM_{2.5}$ was very less. This indicates that some external factors playing the role in particulate matter concentration in the mining region. Thus, a multiple regression analyses conducted with the consideration of five meteorological parameters (temperature, relative humidity, wind speed, solar radiation, and precipitation). The multiple regression results indicated that the regression coefficients were significantly improved (from $R^2 = 0.01$ to $R^2 = 0.6$) but not up to the mark. The future scope of the research is to identify more number of factors that influence the $PM_{2.5}$ concentrations in the mining regions.

***Key words: $PM_{10}$; $PM_{2.5}$; Aerosol Optical depth; MODIS***

# Contents

# List of Figures

# List of Tables

## Chapter 1

# Introuction

## 1.1 Backround

There are millions of solid and liquid particles suspended in the atmosphere (Aïssani & Mokhnache, 2012). These ubiquitous tiny matters are known as aerosols. They are present everywhere in the ecosystem in between. They move in the atmosphere from the earth's surface to the stratosphere. Their sizes are in the ranges of a few nanometers to several tens of micrometers. In spite of their small size, they have the significance importance in atmospheric chemistry, physics, and the biosphere. They are emitted into the atmosphere through natural and anthropogenic sources, still there are some aerosols which are formed through various physical and chemical processes. Aerosols broadly classified into two categories by their sources of generation viz. primary particles and secondary particles (Li et al, 2015). The particles which are directly emitted as liquids or solids from sources come under primary particles. For example, biomass burning, incomplete combustion of fossil fuels, volcanic eruptions, and wind-driven or traffic-related suspension of the road, soil, and mineral dust, sea salt, and biological materials (plant fragments, microorganisms, pollen, etc.). Secondary particles, on the other hand, are formed by gas-to-particle conversion in the atmosphere (new particle formation by nucleation and condensation of gaseous precursors).

The size of aerosols are so small that it is not possible to feel their presence, but their presence can be felt when these particles are sufficiently large. They scatter and absorb sunlight. This reduces visibility (haze) and reddens sunrises and sunsets (Willeke & Whitby, 2012).

There are different names of aerosols based on their shape size and chemical compositions. According to toxicologists, they are ultrafine, fine, or coarse matter. Meteorologists, typically use particulate matter. Depending on their sizes, they are divided into Particulate matter less than 10 micrometers ($PM_{10}$) and particulate matter less than 2.5 micrometer ($PM_{2.5}$). According to Climatologists, primary aerosol groups comprises of organic carbon, black carbon, sulfates, nitrates, mineral dust, and sea salt. In practice, many of these forms of aerosols do not found in the atmosphere as these are clump together to form complex mixtures. It is common, for example, particles of black carbon from soot or smoke to mix with nitrates and sulfates, or to coat the surfaces of dust, creating hybrid particles (Voiland, 2010).

## 1.2 Sources of Atmospheric aerosols

The atmospheric aerosols are the complex and dynamic mixture of solid and liquid particles from natural and anthropogenic sources. The regular foundation aerosols are available without human action while anthropogenic sources dominate the urban airborne. In both cases, primary particles are consistently discharged into, and chemical reactions formed the secondary particles in the atmosphere. The environmental airborne terribly influences our lives. It affects global weather, nearby climate, visibility, and individual well-being (Andreae & Crutzen, 1997). The majority of the natural aerosols come from particulate mass from soil dust, volcano aerosol emissions. Usually, the large particles originate from the direct anthropogenic emissions. Such particles fall out near the source due to heavy weight. The other sources produce fine particles which are light in weight. Those particles continue to exist in airborne phase for many days, long enough to travel global distances. Among anthropogenic sources, combustion releases such particles.

### 1.2.1 Natural aerosols

Soil salt, sea salt, botanical debris, volcanic dust, forest fires are some common sources of natural aerosols. The natural sources of aerosols can be divided into two groups: Stratosphere aerosols and troposphere aerosols.

The stratosphere ranges 11 to 50 km from the earth surface. There are some major volcanic eruptions which injected $SO_2$ into the stratosphere layer and the chemical reaction (gas to gas particle conversion) form sulphuric acid droplets from $SO_2$. These droplets are the primary precipitation nuclei in the formation of atmospheric cloud.
The natural aerosols in troposphere (the region below an altitude of 11 km) depends on direct emissions and gas-to-particle formation from natural sources. On a mass basis, direct emissions of salt from oceans, vegetation, and desert dust are the various sources of tropospheric aerosol. The concentration of tropospheric particles varies inversely with altitude i.e. at high altitude low concentration of aerosols and vice versa.

### 1.2.2 **Anthropogenic aerosols**

In the urban areas generation of aerosols are mainly dominated by anthropogenic sources. Their concentrations in urban areas are very high. In heavily polluted cities, industrial, mining areas, their mass varies from a few tens of $\mu g/m^3$ to one $mg/m^3$. According to their size, they are categorized into modes. There are three modes of particle size distribution data for the urban aerosol: the nuclei, accumulation, and coarse particle modes. Most of the particles found in the nuclei mode by count, but their mass is split between the accumulation and coarse particle modes.

Combustion sources emitted tiny particles (particles size less than 0.1 micrometers). These particles formed in the atmosphere by gas-to-particle conversion come under nuclei mode. They are usually found near highways, industrials areas and combustion sources. The nuclei particles have relatively short lifetimes in the atmosphere as they coagulate rapidly and end up in the accumulation mode.

Smog particles, combustion particles, and coagulated nuclei-mode particles come under accumulation mode. Their size ranges from 0.1 micrometers to 2.5 micrometers. Particles in this mode are tiny but they coagulate too slowly to reach the coarse-particle mode. Therefore, they have a relatively long lifetime to reach the atmosphere, and they are the reason for most of the visibility effects of the atmospheric aerosols. The nuclei and accumulation modes together constitute “fine” particles.

The coarse-particle mode (particle size greater than 2.5 micrometers) includes the wind-driven dust, large salt particles from the sea, and mechanically generated anthropogenic particles such as those from agriculture and surface mining. Because of their large size, they are heavy in mass. Therefore, the coarse particles readily settle out or impact on the surface. The lifetime of these particles in the atmosphere is only a few hours.

## 1.3 Effects of aerosols

Aerosols have now become an important universal issue due to its direct and indirect effects on environment and human health (Poschl, 2005).

**Direct effect**

In the direct effects of aerosols, the tiny particles block the incoming sunlight to the earth surface. Depending on their physical properties they scatter or absorb the sunlight to varying degrees and make the environment haze. According to climatologist, they affect the earth's radiation field. Pure sulfates and nitrates reflect nearly all radiation they encounter and make the atmosphere cool whereas black carbon absorbs radiation and warm the atmosphere. Organic carbon (brown carbon or organic matter) has a warming effect on the atmosphere based on the brightness of the underlying ground. The behaviour of the dust grain to radiation depends on the composition of the minerals that comprise (Voiland, 2010).

**Indirect effect**

The pollution-rich clouds contain more numerous but smaller water droplets. They scatter more light and become more reflective. That is why the droplets make clouds look brighter than they would otherwise be. This cloud brightening effect is called the "cloud albedo effect." The brighter clouds block sunlight from reaching Earth's surface, shading the planet and producing net cooling. This effect can also influence the temperature at which liquid cloud droplets freeze, further affecting the ability of the cloud to precipitate. Altogether, these are called "Indirect Aerosol Effects." (Huang, et al, 2014)

### 1.3.1 Effects on human being

Aerosols exist in different forms. Airborne dust, mists, smokes, fumes are some of them. In the occupational setting, all these forms may be substantial because they relate to a wide range of occupational diseases. The finer the particles the more dangerous they are. The fine particulate matters less than 10 micrometers or less than 2.5 micrometers have a very significant influence on human health. They contribute to a variety of diseases. From the epidemiological studies, it is clear that there is a strong relation between the exposure to fine particulate matter and its health impact. Most of the fine and ultrafine materials generate from combustion sources. They are the mixture of elemental and organic carbon, metals, and inorganic compounds such as sulfates. In the process of respiration, the particles enter into our body through the nose. Due to their small size, they cannot be checked by nose hairs and thus enters into the lungs. They also penetrate into the circulatory system and lodge in organs such as liver and heart. The symptoms of health impacts are of both acute and chronic. The acute diseases are asthma and bronchitis. Chronic diseases are irritation and inflammation of respiratory tract, which can potentially lead to cancer (Bickis, et al., 1998). According to the estimation from the World Health Organization (WHO), particle pollution contributes to approximately 7 million premature deaths each year, making it one of the leading cause of worldwide mortality (Media centre, 2014).

### 1.3.2 Effects on vegetation

Vegetation is also affected due to aerosols through direct and indirect pathways. The leaf usually filters the coarser particles at much higher rates, but it fails when the particles are lesser in size. The amount of PM deposited on plants varies significantly spatiotemporally. Dust affects plant physiology at both physically as well as at the chemical and biochemical level. Fine dust particles can clog stomata openings, reduce photosynthesis, increases leaf temperature and increase transpiration (Ulrichs, et al, 2008).

The particulate matter indirectly enters the plant through the root system. The deposition of pollutant particulate matter on soils and surface water can cause a change in the nutrient content of the soil in the nearby area of the plant. This changes the soil conditions and hence leads to an indirect effect of air pollutants on vegetation and plants (Jimoda, 2012).

### 1.3.3 Effects on visibility

Visibility is a major factor because low visibility can interrupt the traffic movement impacting business, public safety, and tourism. Visibility degradation is one of the most promptly seen impacts of fine particulate matter. The particulate matters retain and disperse the radiance and therefore diminish visibility. The most quick and evident effect of urban air contamination is its impairment of visibility. Most urban communities on the planet are encountering large amounts of visibility degradation due to high outflow force and unfriendly meteorology. This high discharge force is as an aftereffect of fine particles that interact more strongly with visible radiation due to their diameter being similar to that of light wavelengths (Chiapello, et al, 2005).

In most urban climates, visual degradation is to a great extent connected with the presence of aerosol particles. This is because aerosols interact with visible light in a different manner to gases. Henceforth, airborne seems shine against a blue sky when a viewer is looking towards the sun and dim when the sun is behind the viewer. It is found that relative humidity has substantial effects on the disappearance properties of the aerosol as a result of absorption and water uptake capacities of the various mineral aerosol properties.

Air visibility is a precious natural resource with respect to the beauty of the environment and economic advantage. One of the fundamental explanations behind the tenacity of the visibility issue is the absence of strategies that can quantitatively indicate how different sources contribute to visibility impairment. Past studies have demonstrated that secondary particulates that are generated in the atmosphere from the reaction of precursor gases contribute remarkably to visibility impairment in polluted areas. The diminishment of the visual extent and the discolouration of the sky are brought on by the diffusing and absorption of light due to gases and suspended particles. In a perfect and fresh environment, visibility is only limited by light scattering due to gas molecules (Rayleigh scattering), resulting in a visual range of approximately 300 km. In polluted areas, anthropogenic pollutants significantly reduce the visual range (Jimoda, 2012).

### 1.3.4 Effects on materials

An essential issue of particulate matter pollution is the soiling of surfaces. Henceforth, the procedures of cleaning, painting and repairing exposed surfaces turn into a monetary weight. Corrosive particles can seriously debase work of art and historical monuments and result in the lessening of their aesthetic appearance and life range. Chemical degradation of materials due to deposition of atmospheric acid particles is an essential point of damage to property. Particulate matters make the streets, sidewalks and floors dusty. Thus, they must be cleared or cleaned more frequently, and clothing should likewise be washed all the more regularly.

## 1.4 Monitoring methods of aerosols

Monitoring of aerosols is important for air quality point of view. A better understanding of aerosol particles helps in the prediction of local and global climate. The concentration of aerosols in the air, the source of their generation, their properties and effects can be found out by monitoring them.

Aerosol properties have been typically acquired from in-situ measurements and column integrated optical depth measurement. Aerosols optical depth (AOD) is a column integrated optical depth measurement of aerosols. There are many ground-based networks and satellite-based sensors to measure the aerosol optical depth.

### 1.4.1 Ground-based aerosol optical depth measurement

The most popular ground-based AOD retrieval systems are sunphotometry and lidar. The first one is a passive optical system that measures the extinction of direct-beam radiation in distinct wavelengths and retrieves the aerosol contribution to the total extinction. The second one is an active optical system transmits light into the atmosphere and then collects the backscatter light signals to retrieve the aerosol attenuation in total columnar atmosphere. Ground-based sunphotometry radiometer uses the down-welling radiances of solar radiation to recover total columnar AOD in a specific area.

There are a different types of ground-based aerosol monitoring networks (Dayou, et al, 2014). These are:

- Aerosol Robotic Network (AERONET)
- Multi-Filter Rotating Shadowband Radiometer (MFRSR)
- China Meteorological Administration Aerosol Remote Sensing Network (CASRNET)
- Maritime Aerosol Network (MAN).

### 1.4.2 Satellite-based aerosol optical depth measurement

The satellite-based monitoring is getting popular day by day because the facts provided by the satellite is timely and global in coverage. Currently, there are different research team developing satellite-based aerosol optical depth retrieval techniques. There are different types of algorithms has been developed based on the different characteristics of satellite sensiors. Satellite-based instruments designed for aerosols retrieval (Kokhanovsky, et al., 2007) are as follows:

- Moderate Resolution Imaging Spectro-radiometer (MODIS)
- Multi-angle Imaging Spectro-Radiometer (MISR)
- Polarization and Directionality of the Earth's Reflectance (POLDER)
- Polarization and Anisotropy of Reflectance for Atmospheric Sciences Coupled with Observations from LIDAR (PARASOL)
- Advanced Very High Resolution Radiometer (AVHRR)
- Along Track Scanning Radiometer (ATSR)
- Advanced Along Track Scanning Radiometer (AATSR)

The characteristics of different satellite instrument is shown in the Table 1.1.

Table 1.1: The characteristics of different satellite instruments.

| Instrument | Satellite/time of measurement | Swath (km) | Channels | Spatial resolution | Multi-angle observation |
|---|---|---|---|---|---|
| MERIS | ENVISAT 10:00 UTC | 1150 | 15 bands 0.4–1.05 μm (0.41,0.44,0.49,0.51,0.56, 0.62,0.665,0.681,0.705,0.754, 0.76,0.775,0.865,0.89,0.9 μm) | 0.3×0.3 $km^2$ | No |
| AATSR | ENVISAT 10:00 UTC | 512 | 7 bands 0.55,0.66, 0.87, 1.6, 3.7, 10.85, 12.0 μm | 1×1 $km^2$ | Yes, 2 angles from the ranges 0–21.732 and 55.587–53.009 degrees |
| SCIAMACHY | ENVISAT 10:00 UTC | 916 | 8000 spectral points 0.24–2.4 μm | 30×60 $km^2$ | No |
| MISR | TERRA 10:32 UTC | 400 | 4 bands 0.446, 0.558, 0.672, 0.866 μm | 0.25×0.25 $km^2$ at nadir and at 0.672 μm 1.1×1.1 $km^2$ in the remaining channels | Yes, 9 angles 0, 26.1, 45.6, 60.0, 70.5° |
| MODIS | TERRA 10:32 UTC AQUA 13:30 UTC | 2300 | 36 bands 0.4–14.4 μm (1):0.659,0.865 (2):0.47,0.555,1.24,1.64,2.13 (3):0.412,0.443,0.488,0.531,0.551, 0.667,0.678,0.748,0.869,0.905,0.936, 0.94,1.375+MWIR(6)/LWIR (10) channels | (1): 0.25×0.25 $km^2$ (2): 0.5×0.5 $km^2$ (3):1×1 $km^2$ | No |
| POLDER | PARASOL 13:33 UTC | 1700 | 8 bands 0.443,0.490*,0.565,0.670*, 0.865*,0.763,0.765,0.91 | 5.3×6.2 $km^2$ | Yes, channels marked with* have a capability to measure polarization |

Source: (Kokhanovsky, et al., 2007)

Satellite acquired column aerosol optical depth (AOD) is a cost effective technique to track and analyse aerosols distribution and effects over a long time span. Moderate Resolution Imaging Spectroradiometer (MODIS) extracted AOD is very suitable for such monitor due to its revisit cycle of 1-2 days as a result a close observation of AOD is possible for a particular area all the time in a year. MODIS is a new generation Imaging Spectroradiometer, which has moderate spectral resolution with 36 spectral bands that cover the wavelength range from 0.4 to 14.4 µm, and three spatial resolutions of 250, 500, and 1000 m, respectively, and a swath of 2330 km.

## 1.5 Formulation of the problem

In general air quality in the mining region is found to be poor and creates various health problems to workers and the peoples residing in the region. Thus, in the present situation air quality measurement is the top priority. The measurement of aerosol level can identify the vulnerable zones concerning high aerosol levels. After measuring the high aerosol areas, different control measures can be taken to control it. Measurement of aerosols and its control required to protect the human health from exposure to high aerosol level. Ground-based monitoring has been restricted to few selected sites, and it is also impossible to establish the monitoring station in each city due to high instrumentation and maintenance cost. The present study focus on the estimation of aerosol optical depth (AOD) level from Moderate Resolution Imaging Spectroradiometer (MODIS) satellites data to solve this problem. Furthermore, the present study also attempts to estimate the $PM_{2.5}$ concentration from the AOD level using regression analysis.

## 1.6 Aims and objectives

The objectives of the present study are as follows:

- Study of AOD levels in mining areas using MODIS satellite images.
- Development of a statistical model to estimate particulate matter in the mining region from AOD level.

## 1.7 Organization of the thesis

The present work focuses on the determination of the AOD levels from MODIS satellite data and to develop a statistical model to estimate a relationship between AOD and particulate matter. This thesis contains 6 number of chapters. They are organised from chapter 1 to chapter 6.

***Chapter 1*** gives the abstract about aerosol and its impacts. It also demonstrate about the MODIS data and AOD level.

***Chapter 2*** presents the detailed literature review on measurement of AOD from MODIS data. This chapter also presents the past studies on PM concentration from AOD level.

***Chapter 3*** explains the materials and method of the proposed research work. It also briefly explains about the study area.

***Chapter 4*** presents the result and discussion of spatio-temporal variations of AOD level in various locations.

***Chapter 5*** explains the methodology for development of statistical model for prediction of PM concentration from AOD level.

***Chapter 6*** explains the outcomes of present study and future scopes of work.

# Chapter 2

# Litrature revew

## 2.1 Introuction

Atmospheric aerosols are the airborne particles both in solid or liquid form in a gas medium. Their sizes varies from nanometers to micrometers. They originate from both natural sources (pollens, sea spray, wind-driven dust, and ash from volcanic eruptions) and manmade sources (mining activities, polluted air from industries, vehicular movements). The aerosols both reflect and absorb the incoming solar light and affect the earth’s radiation amount (Bian & Zender, 2003). They are one kind of geophysical parameters that estimate the earth’s energy balance and hydrological cycle. They make the environment haze by reducing the visibility and decline the human health by various diseases. The effects of aerosols can be understood by studying their characteristics (magnitude, structure, mass, diffusion, and optical properties) on local to worldwide scales (Chin, et al., 2009).

The effects of aerosols on ultraviolet (UV) radiation is a major topic in many stuies. Because the influence of UV radiation on human, the atmosphere strongly depends on the characteristics and quantity of aerosol in the atmosphere. Overexposure to UV-B radiation can lead to severe health issues for humans such as skin cancer, accelerated aging of the skin, cataract, photokeratitis and changes in the immune system (Lopo, et al, 2014). There are many respiratory diseases due to overexposure to dust particles. For examples chronic bronchitis/pneumoconiosis. It can be collagenous/non-collagenous (non-fibrogenic). So, the monitoring of PM is very much essential to check its adverse impact on human health.

## 2.2 Atmospheric dust

Dust are one of the forms of aerosols. The minute particulate matters are known as dust. Several natural and anthropogenic affairs such as volcanic eruptions, soil particulates lifted by weather, mining operations, automobile exhausts, construction activities, etc. are the reason for this suspension. The size of particulates characterizes the particulate matter in the air. The finer the particulate matter there is the chances of it being getting suspended and carried further while the coarser settles down quickly. According to their sizes, they are of following types (Fact sheet, 2011).

**SPM**

The minute particles that may be suspended in the medium are suspended particulate matter. SPM in the air are the airborne solid and liquid particles. They are of any sizes.

**$PM_{10}$**

The particulate matter which has the diameter less than 10µm. They are commonly called as coarse particles. They generate from roads, industrial activities.

**$PM_{2.5}$**

The particulate matter which has the diameter less than 2.5µm is called $PM_{2.5}$. They are also known as fine particulate matter. They contain secondary aerosols, combustion particles, re-condensed organic metallic vapours and acid components.

**Ultrafine Particles**

Ultrafine particle (UFPs) are particulate matter of nano-scale size (less than 100 nanometers in diameter).

## 2.3 Mine dust

Mining activities mostly produces dust which results due to the mining practices and ore processing. In most of the cases the dust produced by the mine is fugitive in nature i.e. the sources can't be easily defined and mainly consists of disturbances of surface but drilling, blasting, transportation are the common sources dust generation in mines. Now a days to maintain the energy balance, the mining activities are growing at a phenomenon rate. Large opencast mines are operated and different heavy machineries are used. They contribute a large amount of particulate matter to the environment.

The generation of dust in mining is not uniform and their effects also. There are different types of mines (Coal mine, Iron mine, Bauxite mine etc.) and they produces different types of dust. There are several operations in mines which contributes to the particulate matter generation. They are:

- Removable of vegetation and top soil
- Vehicular movement for transportation
- Drilling blast holes
- Blasting operation
- Stockpiling of the overburden
- Extracting, transporting and dumping ores
- Cutting the ore using surface miners
- The ore crushing process
- The ore benefication process
- Workshop activities
- Rehabilitation and backfilling etc.

The different particulate matters generated due to these activities are commonly called as mine dusts. As compared to underground mining, the opencast mining produces large amount of dust. In open cast mines the use of large equipment (dumpers, draglines, surface miner, and shovels etc.) for handling overburden, drilling, blasting, crushing and transportation etc. produces large amount of particulate matters.

The constitution of dust produced in mines based upon the mineral content of the ore. Depending upon the harmfulness of dusts, they can be categorised in the following manner.

- Carcinogenic Dusts
- Toxic aerosols (poisonous to body organs and tissues etc.)
- Radioactive dusts
- Fibrogenic Dust
- Explosive dusts
- Nuisance dusts

**Health diseases due to mine dust**

Avoiding dust generation in mines is impossible. When these dust particles become airborne, bring critical changes to the environment and ecology of the mining zones and its vicinity. The particulate matters produced due to mining activities when invade into lungs create "Pneumoconiosis". It is an occupational lungs disease caused by the inhalation of dust, often in mines. Depending upon the type of dust, the disease is given different names: (Karkhanis & Joshi, 2013), (US department of health and human services, 1995)

- **Coal worker's pneumoconiosis (CWP):** It is also known as black lung disease and is caused by accumulation of coal dust in the lungs and the tissue's reaction to its presence. It is commonly found in coal miner and those who work with coal. The disease is divided into two categories: simple coal worker's pneumoconiosis (SCWP) and complicated coal worker's pneumoconiosis (CCWP). Coal dust inhalation is also related to the development of chronic obstructive pulmonary disease that contributes to increased mortality among these patients.
- **Asbestosis:** It occurs due to long-term heavy exposure to asbestos. The incidence of asbestosis varies with the cumulative dose of inhaled fibers; the greater the cumulative dose, the higher is the incidence of asbestosis. It is a chronic inflammatory medical condition affecting the parenchymal tissue of the lungs. Dyspnoea is the most common symptom and worsens as the disease progresses. Patients may have a dry (i.e., nonproductive) cough.
- **Silicosis:** Silicosis is a disable, non-reversible fibrotic disease of the lungs caused by inhalation of dust containing free crystalline silica. Mining, tunneling, sandstone industry, stone quarrying and dressing, iron and steel foundries and flint crushing are the occupations most closely related to the hazards of silica exposure. Silicosis is characterized by the presence of small discrete nodules exclusively distributed in the upper zones of the lung with a posterior predominance (Colinet, et al, 2010).
- **Siderosis:** It is a non-fibrogenic form of pneumoconiosis due to inhalation of iron particles. It is caused by the accumulation of iron oxide in macrophages within the lung.

## 2.4 Exposure to aerosol and health impact study

Aerosol particles contributes to a variety of human health problems. Industrialization process added various organic and in-organic pollutants in the air. Therefore, dust related diseases are increasing nowadays. Thus, monitoring and control of generation of the aerosol are very much essential. That is why a lot of research work have been done to access the effects of particulate matter on human health.

(Pope Ill, 2000) studied the epidemiology of particulate matter air pollution and the health of human body. Based on the preliminary epidemiologic proof, it is obtained that a systemic exposure to particulate matter induced pulmonary inflammation. There may be cytokine release and altered cardiac autonomic function. The persons experienced from chronic cardiopulmonary disease, influenza, or asthma are in danger of serious morbidity effects from short-term acute exposures and in normal person, there is chance of getting less severe health effects like temporary increases in respiratory symptoms, decreased lung function, or other physiologic changes. Chronic exposure studies propose that in highly polluted atmosphere repeated exposure to fine particulate matters results in average loss of life expectancy.

(Dominici, et al., 2006) studied the particulate matters air pollution and the number of hospital admission for cardiovascular and respiratory diseases. The author composed a national database consists of daily time-series data for 1999 through 2002 on hospital admission rates. The database constructed from the Medicare National Claims History Files for cardiovascular and respiratory outcomes, atmospheric $PM_{2.5}$ concentration, and temperature and dew-point temperature for 204 US urban counties where the population was more than 200000 with 11.5 million Medicare enrolees, living an average of 5.9 miles from a $PM_{2.5}$ monitor. The daily hospital admissions for the necessary identification of cerebrovascular, heart disease, long-term, complicated pulmonary disease, and respiratory illness, and injuries as a control outcome was measured. In the result, the author obtained that there was a short-term increase in hospital admission rates associated with the increase in $PM_{2.5}$. The largest association was for heart failure. Cardiovascular dangers had a tendency to be higher in regions situated in the Eastern area of the United States, which incorporated the Northeast, the Southeast, the Midwest, and the South. Thus, short-term exposure to $PM_{2.5}$ increases the risk for hospital admission for cardiovascular and respiratory diseases.

(Chan, et al., 2009) studied the spatiotemporal analysis of particulate matters and asthma patient visits in Taipei, Taiwan during 2000–2002. The author surveyed everyday patient and emergency visit report from the “Taiwan Bureau of National Health Insurance and air pollution” from the “Taiwan Environmental Protection Administration”. The result showed that during 2000–2002, it was observed that the asthma patient visits a total of 724,075 outpatient. A somewhat higher rate of male visits were watched for the emergency visits (58.5%) than outpatient visits (55.8%). In these two settings, kids (0–15 years) had the most remarkable number of aggregate asthma visits (outpatient: 48.8%, emergency: 46.1%) and those older than 65 years had the lowest number of total visits (outpatient: 16.8%; emergency: 15.1%). The author said that 10 percent increase in PM concentration, asthma outpatient visit rate increased by 0.14 percent.

(Gorai, et al, 2014) applied GIS technique to estimate the relation between air pollution ($PM_{2.5}$, sulfur dioxide and ozone) and asthma disease in New York State, USA during the period 2005 to 2007. The asthma rates were determined from the population of 2005 to 2007 and the number of hospital discharge and emergency department visits of asthma patient. Pearson correlation coefficient was used to compare the annual means of these concentrations and annual variations in asthma. In the result a positive correlation coefficient was obtained between the annual mean concentration of $PM_{2.5}$, and $SO_2$ and the annual rates of asthma discharge and asthma emergency department visit from 2005 to 2007 and a negative value was observed between annual mean concentrations of ground ozone and the annual rates of asthma discharge and asthma emergency visit. In this study, the author said that there was a significant association between airborne concentrations of $PM_{2.5}$ and $SO_2$ and asthma patient among residents of New York State.

## 2.5 **Aerosol Optical Depth**

Aerosol Optical depth (AOD) is a way to measure the atmospheric aerosols. Although, there are different other techniques, measuring aerosols through AOD is one of the most convenient and efficient process. Satellite based AOD measurement is one step forward than ground level monitoring. Satellite data covers the full earth surface whereas the ground level monitoring confined to few particular sites. Aerosol Optical Depth (AOD) measures aerosol distributed within a column of air from the earth's surface to the top of the atmosphere.

The sun photometer measures the voltage (V). The spectral irradiance reaching the instrument is (I). Similarly the spectral irradiance at the top of the atmosphere is ($I_o$) and the voltage measured by the sun photometer at Mauna Loa Observatory in Hawaii is ($V_o$). The total optical depth ($\tau_{TOT}$) can be obtained using Beer-Lambert-Bouguer law. The law is:

$$V(\lambda) = V_0(\lambda)\, d^2 \exp[-\tau(\lambda)_{TOT} * m] \qquad 2.1$$

Where, V = digital voltage measured at wavelength λ

Vo = extra-terrestrial voltage

d = ratio of the average to the actual Earth-Sun distance

$\tau_{TOT}$ = total optical depth

m=optical air mass.

While evaluating AOD some light scattering atmosphere constituents (the optical depth due to Rayleigh scattering, water vapour, and other wavelength-dependent trace gasses) is subtracted from the total optical depth to obtain the aerosol component.

$$\tau(\lambda)_{Aerosol} = \tau(\lambda)_{TOT} - \tau(\lambda)_{water} - \tau(\lambda)_{Rayleigh} - \tau(\lambda)_{O3} - \tau(\lambda)_{NO2} - \tau(\lambda)_{CO2} - \tau(\lambda)_{CH4} \qquad 2.2$$

## 2.6 World Geodetic System 1984 (WGS84)

WGS84 is a terrestrial reference system and geodetic datum. It is Earth-centered and Earth-fixed. It depends on a regular arrangement of constants and model parameters that explains the Earth's size, shape, gravity and geomagnetic fields. It is the reference system for the Global Positioning System (GPS). (International Hydrographic Bureau , 2008)

## 2.7 Giovanni

Giovanni, the Goddard Interactive Online Visualization, and Analysis Infrastructure offer a user-friendly web-based environment. It helps in exploring different remote detecting environmental information. With the help of Giovanni, the user easily obtains remote sensing or model data from around the universe. It skips the overhead works like downloading the data and understanding its complicated formats before starting the desired study. It is very easy to use Giovanni because there is no need to use any particular applications for this, access is provided through a conventional web browser (Leptoukh, et al., 2010).

In the web page, there is "box" for the selection of spatial area via Java image map or by entering coordinates of the area manually. The user also selects the temporal range for the data, one or more parameters from this data set, and the desired output type. Plotting is also very much convenient in Giovanni. There are several colour options available for this. The user can download the entire data set for further local analysis from the links accessible to the data set. After setting the parameters, the result available immediately, but the online manipulation may take several time if large amounts of data are taken.

## 2.8 MODIS satellite

The Moderate Resolution Imaging Spectroradiometer (MODIS) is an instrument designed by NASA (The National Aeronautics and Space Administration) to provide improved monitoring for land, ocean, and atmosphere research (NASA, 2016). It has two sensors as follows:

- Terra (initially known as EOS AM-1)
- Aqua (originally known as EOS PM-1)

Terra satellite orbit around the earth is adjusted that it passes from north to south across the equator in the morning time, while Aqua passes south to north over the equator in the afternoon. The satellites are viewing the entire earth's surface every 1 to 2 days. They acquired the data in 36 spectral bands or groups of wavelengths. These information help in the comprehension of worldwide progression and process happening in the area, in the seas, and in the lower atmosphere. MODIS is conveying a significant role in the building of validated, global, interactive Earth system models which can predict global change accurately enough to assist policy makers in making sound decisions concerning the protection of the environment. MODIS technical specification is listed in the Table 2.1.

Table 2.1: MODIS satellite technical specification

| **Specifications** | **Details** |
|---|---|
| Orbit | 705 km, 10:30 a.m. descending node (Terra) or 1:30 p.m. ascending node (Aqua), sun-synchronous, near-polar, circular |
| Scan Rate | 20.3 rpm, cross track |
| Swath Dimensions | 2330 km (cross track) by 10 km (along track at nadir) |
| Telescope | 17.78 cm diam. off-axis, afocal (collimated), with intermediate field stop |
| Size | 1.0 x 1.6 x 1.0 m |
| Weight | 228.7 kg |
| Power | 162.5 W (single orbit average) |
| Data Rate | 10.6 Mbps (peak daytime); 6.1 Mbps (orbital average) |
| Quantization | 12 bits |
| Spatial Resolution | 250 m (bands 1-2), 500 m (bands 3-7), 1000 m (bands 8-36) Design Life: 6 years |

The aerosol products of MODIS retrieved using dark target algorithms and deep blue algorithms. The Dark-Target algorithms is the older version of aerosol retrieval technique. It measures reflectance wavelength bands covering visible (VIS), near-IR (NIR) and shortwave-IR (SWIR). The products of dark target algorithms are low quality due to low contrast between the surface and the atmosphere. It lacks coverage over arid surfaces because its surface reflectance assumptions are inappropriate. As a result, the new version deep blue algorithms is developed. The deep blue algorithms is very effective in retrieve data over bright-reflecting land surfaces, such as desert, semi-arid, and urban regions etc. This is particularly important over regions of mixed vegetated and non-vegetated surfaces, which may undergo strong seasonal changes in land cover (Ramer, et al., 2005).

## 2.9 Prediction of particulate matter (PM) from MODIS AOD data

There were a lot of studies conducted to establish the relationship between aerosol optical depth (AOD) and particulate matter concentration.

(Justice, et al., 2009) studied the relations between satellite-derived aerosol optical depth and ground based $PM_{2.5}$ measurements in California's San Joaquin valley with the help of MODIS deep blue algorithms. The air pollution in the San Joaquin Valley has exceeded the state and federal particulate matter standards for a long time. Ground level sensors were used to monitor the air quality. This process of monitoring provides accurate result at a particular area, but it was not able to provide a clear information of conditions over large regions. Measurements from satellite imagery have the capacity to provide timely air quality data for large swaths of land. This study included hourly and daily measurement of surface PM to both traditional and Deep Blue-retrieval AOD data from MODIS Aqua satellite. Deep Blue algorithm is a newly developed technique that was applied to all Aqua MODIS data. Additionally, the study analysed the effects of relative humidity, and surface reflectance on differences in PM and AOD measurements. Data from July 4, 2002 to July 6, 2008 were used for this research. They were downloaded from MODIS and CARB for six CARB sites in the San Joaquin Valley: Bakersfield, Fresno, Modesto, Stockton, Tracy, and Turlock as well as two CARB sites outside the valley: San Jose and Yosemite. The result showed that the new deep blue algorithms products, achieved improved correlations when compared to the traditional MODIS AOD product. For Fresno $R^2$ values were 0.178 and 0.019 for Deep Blue and traditional, respectively. Enhanced correlations were obtained using hourly $PM_{2.5}$ totals instead of daily $PM_{2.5}$ averages, suggesting diurnal variation in

$PM_{2.5}$. In the study it was found that both of these factors gave improved $R^2$ values, but further analysis was required to determine the other factors that might be influencing the differences in the AOD and $PM_{2.5}$ readings.

The spatial and time-related variations of $PM_{10}$ ground-based concentration over China and comparison of the result with satellite-retrieved information on the aerosol optical depth (AOD) collected over the period 2003-2005 using a moderate resolution imaging spectroradiometer (MODIS) was studied in (Song, et al., 2009). Annual average $PM_{10}$ concentrations and AOD values were studied. The result showed there was a high spatial correlation, indicating the consistent presence of aerosol level. However, the temporal correlation between the monthly average $PM_{10}$ concentrations and AOD level indicates a regional varies in their seasonality. In the southeastern coast region the correlation coefficients are 0.6 or higher , whereas they are -0.6 or lower in the north-central region. The regional discrepancy is most likely due to the difference in the size distributions of aerosols.

(Zhang et al, 2009) studied the relation between AOD level from Moderate Resolution Imaging Spectroradiometer (MODIS) and $PM_{2.5}$ concentration over the United States for the 10 EPA geographical areas. This work use MODIS AOD from Terra (v4.0.1 and v5.2.6), Aqua (v5.2.6), and hourly $PM_{2.5}$ data of the year 2005-2006. The v4.0.1 MODIS AOD from Terra were obtained from the archive of the IDEA product at the University of Wisconsin, and the Aqua (v5.2.6) data were got from NASA’s LAADS. 36 Hourly $PM_{2.5}$ concentration over the United States was obtained from the IDEA archive, which was accumulated daily from EPA’s AIRNOW server. The match-up process between AOD and $PM_{2.5}$ used in the IDEA product was adopted. For finding the AOD at the position of a $PM_{2.5}$ site, the MODIS AOD pixel that covers this site was pointed and then that value was used. The AOD retrievals demonstrated geographical and seasonal variations in their relation with $PM_{2.5}$. In the results, good correlations were mostly found over the eastern United States in summer and fall. The south-eastern United States shown the highest correlation coefficients at more than 0.6. The south western United States observed the lowest correlation coefficient of approximately 0.2. The seasonal regression relations were derived for each region so that one can use the regression relationships to estimate $PM_{2.5}$ from the AOD retrievals. The AOD retrievals from Terra and Aqua sensors have similar relations with $PM_{2.5}$, and they also have same data coverage. Two kinds of AOD from Terra v4.0.1 and Tera v5.2.6 were also studied and compared in the inversion methods and cloud-screening algorithms. The correlation coefficients between AOD and $PM_{2.5}$ are higher for v5.2.6 than those for v4.0.1 over all EPA regions except region 6 (south). It is possible that the changes in surface reflectance assumptions and aerosol models in the new version did not work well over region 6. The cloud-screening algorithms were found to have much larger impacts on the AOD and $PM_{2.5}$ relation. The AOD retrieval coverage was much larger for v4.0.1 than those for v5.2.6 because of the different cloud screening algorithm. The correlation coefficients were much smaller for the whole dataset for v4.0.1 than those for the subset having one-to-one correspondence with v5.2.6, which indicates that the cloud cover most likely pollutes the extra data in v4.0.1. Overall, AODs from v5.2.6 demonstrate a higher correlation with surface $PM_{2.5}$.

(Dinoi et al, 2010) studied the application of MODIS information for air quality studies over south-eastern Italy. The data of three years from 2006 to 2008 were brought together at two suburban sites. Because of the topographical area, this region is influenced by marine, Sahara desert, and anthropogenic aerosols from Europe mainland. The first evaluation of the regression analysis between daily averaged $PM_{10}$ concentrations and MODIS-AOTs observed that linear simple correlation coefficients (R) vary within the 0.20–0.35 range. The sampling year and the site location affected the result. The $PM_{10}$-AOT correlation becomes stronger R varies from 0.34 to 0.57 when the inspection was limited to measurement of MODIS date in clear sky. Using three years of clear-sky measurements to estimate $PM_{10}$ mass concentrations from MODIS-AOTs, the empirical relation found was: $PM_{10}$ (μg/m$^3$) = 25 (μg/m$^3$) + 65 (μg/m$^3$) × AOT. More than 80% of the contrasts between the deliberate and satellite evaluated $PM_{10}$ mass focuses over the three years are inside ±1 standard deviation of the yearly means. It was also shown that a stronger relationship between $PM_{10}$ and MODIS-AOTs was obtained when the AOT was divided by the product of the mixing layer height with the ground wind speed and the analysis restricted to clear sky MODIS measurements.

Lee et al,2011) studied the prediction of $PM_{2.5}$ from MODIS data. Epidemiological studies reveal that there are various types of diseases due to particulate matters. But due to unavailability of sufficient data, there are the error in the study. The main reason for this insufficient data is due to a less number of $PM_{2.5}$ monitoring station within the study area. Thus, for this reason, satellite extracted information can be used to increase in size of spatial coverage simultaneously improving our potential to estimate location-or subject-specific exposures to $PM_{2.5}$. Another procedure was developed to track aerosol optical depth (AOD) information from the Moderate Resolution Imaging Spectroradiometer (MODIS). Hence, this method was adopted to anticipated daily $PM_{2.5}$ level in the New England region. The AOD data from MODIS satellite relating to the New England were recovered for the year 2003, and $PM_{2.5}$ concentrations measured at 26 US "Environmental Protection Agency" (EPA) were used to estimate the AOD level. A blended impacts model which permits everyday variability in day by day $PM_{2.5}$ and AOD relationships was utilized to predict the area particular $PM_{2.5}$ levels. $PM_{2.5}$ concentrations measured at the ground level monitoring sites were compared to the satellite-retrieved data. From the comparison of the result between the observed and predicted concentrations, it was concluded that the proposed new calibration approach can be used for getting MODIS AOD data.

(Lee et al, 2012) studied on the use of satellite-based aerosol optical depth and spatial data to predict ambient $PM_{2.5}$ concentrations in the New England region of U.S. during the period 2000-2008. In this researh satellite imagery was taken to estimate $PM_{2.5}$ concentrations. In first, the AOD levels were calculated by introducing an AOD daily calibration approach through the use of mixed effects model. Secondly, the models were developed that combine AOD and ground monitoring data to predict $PM_{2.5}$ concentrations during non-retrieval days. The statistical models predicted surface $PM_{2.5}$ concentrations with reasonably high $R^2$ (0.83) and low percent mean relative error (3.5%). The method demonstrated that remote sensing can be a very useful tool in the fields of environmental monitoring and human exposure assessment".

(Kanabkaew, 2013) studied the prediction of hourly particulate matter concentrations in Chiangmai, Thailand Using MODIS Aerosol Optical Depth and ground-based meteorological Data. Aerosol optical depth (AOD) data were collected from MODIS-Tera platform and hourly $PM_{2.5}$ and $PM_{10}$ data were collected from the Pollution Control Department. The relationship between AOD and hourly PM over Chiamgmai was done by first Simple linear regression and then in multiple linear regression with ground-based meteorological data correction. The data used for the statistical analysis were from 2012 (January-April). Result revealed that AOD and hourly PM in simple linear regrssion were positively correlated with the coefficient of determination. For $PM_{2.5}$ the value of $R^2$ is 0.22 and for $PM_{10}$ it is 0.21. There was a significant improve in the relationship between AOD and hourly PM when meteorological correction (relative humidity and temperature) was done. In multiple linear regression, the co-efficeint of determination ($R^2$) was 0.77 and 0.71, for $PM_{2.5}$ and $PM_{10}$ respectively.

(Kim et al, 2013) studied the spatiotemporal variations in the associations between hourly $PM_{2.5}$ and aerosol optical depth (AOD) from MODIS sensors on terra and aqua across the contiguous United States during the year 2005. The result showed that the concentrations of $PM_{2.5}$ varied to a significant value by geographic location. The correlation was stronger in the summer and fall than that in the winter and spring. Overall, it was obtained that AOD level were significantly associated with $PM_{2.5}$ concentrations in all states except Colorado.

(Zheng et al, 2013), analysed the spatial and temporal variability of $PM_{10}$ concentrations using MODIS aerosol optical thickness in the Pearl River delta region, china. Characterization of spatial and temporal disparity of PM is very critical. In this research work, Aerosol Optical Thickness data obtained from MODIS satellite were used to analyse the spatial and temporal variations of $PM_{10}$ pollution in the “Pearl River Delta” (PRD) region. Measurements were taken from 6 ground monitoring sites in this area, with corrections by meteorological conditions (relative humidity correction and vertical correction). The areas selected for model building are uniformly distributed in the space. Three years of diurnal averaged $PM_{10}$ concentrations data were obtained and at the same time corresponding daily MODIS-AOT values also retrieved. The data were used for regression analysis from January 2006 to December 2008. Seasonal linear regression models between 1-km retrieved MODIS AOT data and ground $PM_{10}$ measurements were developed for the PRD region and were subjected to a validation against observations from the regional air monitoring network in this region, with an overall error of less than 50%. In the result, it was found that there were significant improvements on the correlations between ground $PM_{10}$ concentrations and MODIS AOT after vertical and humidity corrections. The R value increases from 0.163–0.353 to 0.234–0.549 for all development sites in the PRD region. In the urban sites higher correlation coefficients($R = 0.466$) and slopes (Slope =68.12) were observed than suburban sites. In suburban site($R = 0.324$, Slope = 37.98). Also, there is an increase in correlation coefficients in summer ($R = 0.453$) than that of spring ($R = 0.392$) and winter ($R = 0.200$). Regardless of the restrictions of this work, the outcomes exhibit the adequacy of recovering remote sensing information for characterizing regional aerosol pollution with the ground level measurements.

(Seo, et al., 2015), studied the $PM_{10}$ concentration level over seoul by utilising multiple empirical models with AERONET and MODIS data. Various empirical linear models were developed to estimate the surface-level $PM_{10}$ concentration. The concentration was estimated using “Aerosol Robotic Network” (AERONET), “Sun-photometer” and “Moderate-Resolution Imaging Spectroradiometer” (MODIS), where the data were collected in Seoul during the “Distributed Regional Aerosol Gridded Observation Network” (DRAGON)-Asia campaign from March to May 2012. An observed relationship between the $PM_{10}$ concentration and the aerosol optical depth (AOD) was accounted for by several parameters in the empirical models. The boundary layer height (BLH), relative humidity (RH), and effective radius ($R_{eff}$) of the aerosol size distribution was also used here in this empirical modelling. Among other models, the model which includes both BLH and $R_{eff}$ produced the highest correlation. That means there was the strong influence of BLH and $R_{eff}$ on the $PM_{10}$ estimations. In the meantime, the effect of RH on the relationship between AOD and $PM_{10}$ found to be very much mow during the campaign period (spring). When both AERONET and MODIS data sets were used in the estimation $PM_{10}$ concentration, the highest correlations between measured and estimated values were found for the residential area and the poorest correlations were obtained for the near-source (NS) site type. Significant seasonal variations of empirical model performances for $PM_{10}$ estimation were discovered utilizing the information gathered at Yonsei University over a period of 17 months including the DRAGON campaign period. The best correlation between measured and estimated $PM_{10}$ concentrations was obtained in winter, due to the presence of a motionless air mass and low BLH conditions. That created in relatively homogeneous aerosol properties within the BLH. On the other hand, the poorest correlation between measured and estimated $PM_{10}$ concentrations was found in spring, due to the influence of the long-range transport of dust to both within and above the BLH.

## Chapter 3

# Materials and methods

## 3.1 Study area

The present study performed on the mining region of Odisha state shown in the Figure 3.2. The latitude and longitude of the state of the state is 17° 49' N - 22°0 34' N & 81° 29' E-87° 29' E respectively. It is one of the 29 states of India, located on the eastern coast. The population of the state is 36,706,920 and the area is 155,707 square kilometer. It is surrounded by the states of Jharkhand to the north, West Bengal to the north-east, Chhattisgarh to the west and northwest, and Andhra Pradesh to the south and southwest. Odisha has 485 kilometers (301 mi) of coastline along the Bay of Bengal to its east, from Balasore to Malkangiri. Area basis, Odisha is the 9th largest state and population wise it is 11th (Official web portal Odisha, 2016). The coastline area of the state is greatly affected by the sea spray.

### 3.1.1 Climate condition

Odisha is situated south of the Tropic of Cancer. So the atmosphere of the state is tropical bringing about excess rise in temperature during the months of April-May. But, the Eastern Ghats of the state experience a cold climate. There is three main seasons in the state. They are Summer season (March to June), Rainy Season (July to September) and the Winter (October to February). The western districts of the state Sundergarh, Sambalpur, Baragarh, Bolangir, Kalahandi and Mayurbhanj are hot almost throughout the year with peak temperature remains between 40-46° C and in winter, it is very cool. The districts nearer to coast, the climate is highly humid. In the summer prek temperature ranges between 35-40° C and the minimum temperatures are typically between 12-14° C. Winter is not very severe. But in some areas in Koraput and Phulbani severe cold is experienced, where the least temperature may drop to 3-4° C. The average rainfall in the state is 150 cm that is due to the south west monsoon from July to September. The month of July is the wettest and the major rivers may get flooded. The state also encountered little rainfall from the retreating monsoon in the months of October-November. January and February remain dry (NIDM Odisha, 2016).


Figure 3.1: Odisha state

### 3.1.2 Mineral, mines, and industries

Orissa is rich in its mineral reserves occupying an important position on the country. The reserves include 24% coal, 28% Iron ore, 59% Bauxite and 98% Chromite of India's aggregate deposits. This relative advantage of the state has attracted the notice of many mining and metallurgical industries. In Orissa, industrialization began soon after independence. The coal mines at Talcher and Ib valley were the oldest mines in the state. After nationalization of coal in 1975 and the national policy on energy sector, many power plants have come up in the state.

Major industries in Orissa right now are steel plants at Rourkela, Kalinga Nagar, and Jharsuguda. Aluminum company at Angul with its Alumina Plant at Damanjodi. There is also Thermal power plants at Talcher & Ib Valley area. In addition to that there is Fertilizer plants, Pulp and paper industries, Ferro alloys plants, cement plants in the state. The state can be divided into twelve industrially active zones / areas based on minerals namely (Department of Steel & Mines Odisha, 2016):

- Iron & Steel plant, Cement, Rolling mill & refractories and chemicals at Rajgangpur.
- Thermal power, coal mines at Ib valley area.
- Aluminum plant, rolling mills at Hirakud area.
- Thermal power plant, Aluminum plant, Coal washeries, Coal mines at Talcher-Angul area.
- Ferro alloys, Thermal power, pulp and paper, coke oven at Choudwar area.
- Pulp and paper, ferro alloys, rubber industries at Balasore area.
- Stone crusher, coke oven at Chandikhol.
- Integrated steel, ferro alloys, rubber industries at Duburi.
- Fertilizer, sea food processing, petroleum coke at Paradeep area.
- Stone crusher at Tapang area.
- Iron, sponge iron, ferro alloys, iron ore crusher, mineral processing at Joda Barbil area.
- Pulp and paper, ferro alloys at Rayagada area.

**The problem**

The increasing mining activity, industrialization, and changing lifestyle has welcome many types of air pollution. The atmosphere of Orissa has transferred incredibly in last few years. So it’s an urgent need to monitor and check the air pollution before it goes worst.

## 3.2 Data type and sources

In the present study, the types of data used are MODIS satellite data for optical measurement of aerosol, particulate matter less than 2.5 micrometers in size ($PM_{2.5}$), and meteorological data from the development of prediction model using linear and multiple regression analysis. The characteristics of data and its sources are discussed below:

### 3.2.1 MODIS data

MODIS (Moderate Resolution Imaging Spectro-radiometer) is an extensive program using sensors on two satellites that each provide complete daily coverage of the earth. The data have a variety of resolutions; spectral, spatial and temporal. MODIS products are available at different processing levels. They are categorised as level 1, 2, 3. Level 1 is geolocated and calibrated brightness temperatures and radiances, level 2 is derived geophysical data products, and the level 3 is gridded time average products. There have been six MODIS data collection processed since MODIS/ Terra launched in early 2000. The collection versions are 001, 003, 004, 005, 051 and 006.

There are three Level-3 (Global Gridded) MODIS Atmosphere products collected from two platforms. Statistics are summarized global grid for daily, eight-day, and monthly temporal periods. The Level-3 MODIS Atmosphere products are:

The **Daily Global Joint Product**: It contains roughly 600 statistical datasets derived from Level-2 MODIS Atmosphere parameters that are summarized over a 24-hour (00 to 00 GMT) period. The ESDT names are MOD08_D3 (Terra) and MYD08_D3 (Aqua).

The **Eight-Day Global Joint Product:** It contains roughly 800 statistical datasets derived from Level-2 MODIS Atmosphere parameters that are summarized over an 8-day period. The ESDT names are MOD08_E3 (Terra) and MYD08_E3 (Aqua).

The **Monthly Global Joint Product:** It contains roughly 800 statistical datasets derived from Level-2 MODIS Atmosphere parameters that are summarized over a monthly period. It should be noted that the content of this product is identical to the Eight-Day Global Joint Product, except for the time period covered. The ESDT names are MOD08_M3 (Terra) and MYD08_M3 (Aqua).

### 3.2.2 PM$_{2.5}$ concentration

In the present study, the particulate matter dust data were taken from the Mahanadi Coalfields Limited (MCL), Orissa. It is the major coal producing company in the state. There are two coal-bearing basins. One is Ib-river coal fields, and another one is Talcher coal fields. (MCL Odisha, 2016)

In Ib-river coal fields, there are four coal areas. They are Basundhara, Ib-valley, Lakhanpur, and Orient. There are six coal areas in Talcher coalfields. They are Bharatpur, Balarampur, Jagannath, Kaniha, Lingaraj, Talcher. The coal mines under MCL in Odisha state was shown in the Figure 3.2. The mines along with their location are presented in the Table 3.1

Air pollution data for different areas of Mahanadi Coalfields limited (M.C.L) were collected for one year period from April 1st, 2014 to May 31st, 2015. These data were used to establish the relation between MODIS AOD level and particulate matter concentration.

### 3.2.3 Meteorological data

The branch of science that deals with the atmosphere of a planet particularly that of the Earth is called Meteorology. The most important application of which is the analysis and prediction of weather. Meteorological science explains the meteorological phenomena like rain, drought, hurricane, etc. Important meteorological parameters are temperature, relative humidity, wind speed, precipitation, and solar radiation. These data were retrieved from the open source (Source: http://globalweather.tamu.edu/). The atmospheric weather condition greatly influences the aerosols distribution. Thus in the relation between the concentration of aerosol and AOD level, weather condition plays an important role. The data were retrieved for locations coincidental to PM monitoring stations.

Table 3.1: Coal mines in Odisha and its location

| | Mine area | Coal mines | Longitude (decimal degrees) | Latitude (decimal degrees) |
|---|---|---|---|---|
| **Ib river coalfields** | Basundhara area | Kulda OCP | 83.73596 | 22.031884 |
| | | Basundhara (W) OCP | 83.730338 | 22.059951 |
| | Ib valley area | LajkuraOCP | 83.905556 | 21.821389 |
| | | Samaleswari OCP | 83.8833 | 21.7833 |
| | Lakhanpur area | Belpahar OCP | 83.871814 | 21.798416 |
| | | Lakhanpur OCP | 83.770252 | 21.763858 |
| | | Lilari OCP | 83.847778 | 21.781667 |
| | Orient area | Orient Area | 83.908611 | 21.845278 |
| **Talcher coalfields** | Bharatpur Area | Bharatpur OCP | 85.123333 | 20.956667 |
| | | Chhendipada OCP | 84.876389 | 21.075833 |
| | Balaram Area | Hingula OCP | 85.027989 | 20.967125 |
| | | Balaram OCP | 85.073699 | 20.955048 |
| | Jagannath Area | Bhubaneswari OCP | 85.175572 | 20.947036 |
| | | Ananta OCP | 85.146667 | 20.961111 |
| | Kaniha Area | Kaniha OCP | 85.046883 | 21.104508 |
| | Lingaraj Area | Lingaraj OCP | 85.194384 | 20.959615 |
| | Talcher Area | Talcher Colliery | 85.175047 | 20.950698 |

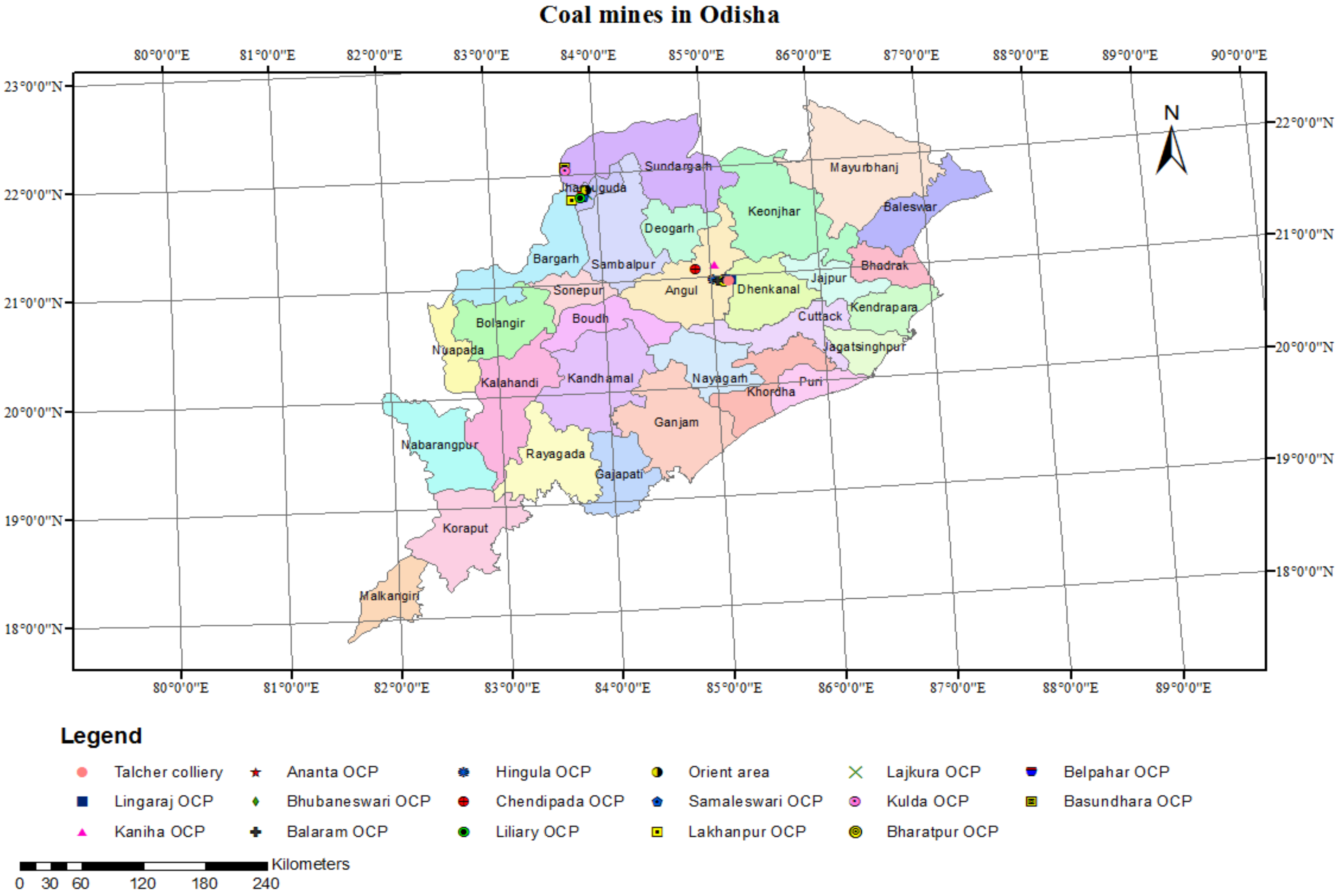



Figure 3.2: Coal mines area of Odisha

## 3.3 Methods

The step involves in the present study is represented by a flowchart as shown in the Figure 3.3. MODIS Aqua satellite data were used for this study.

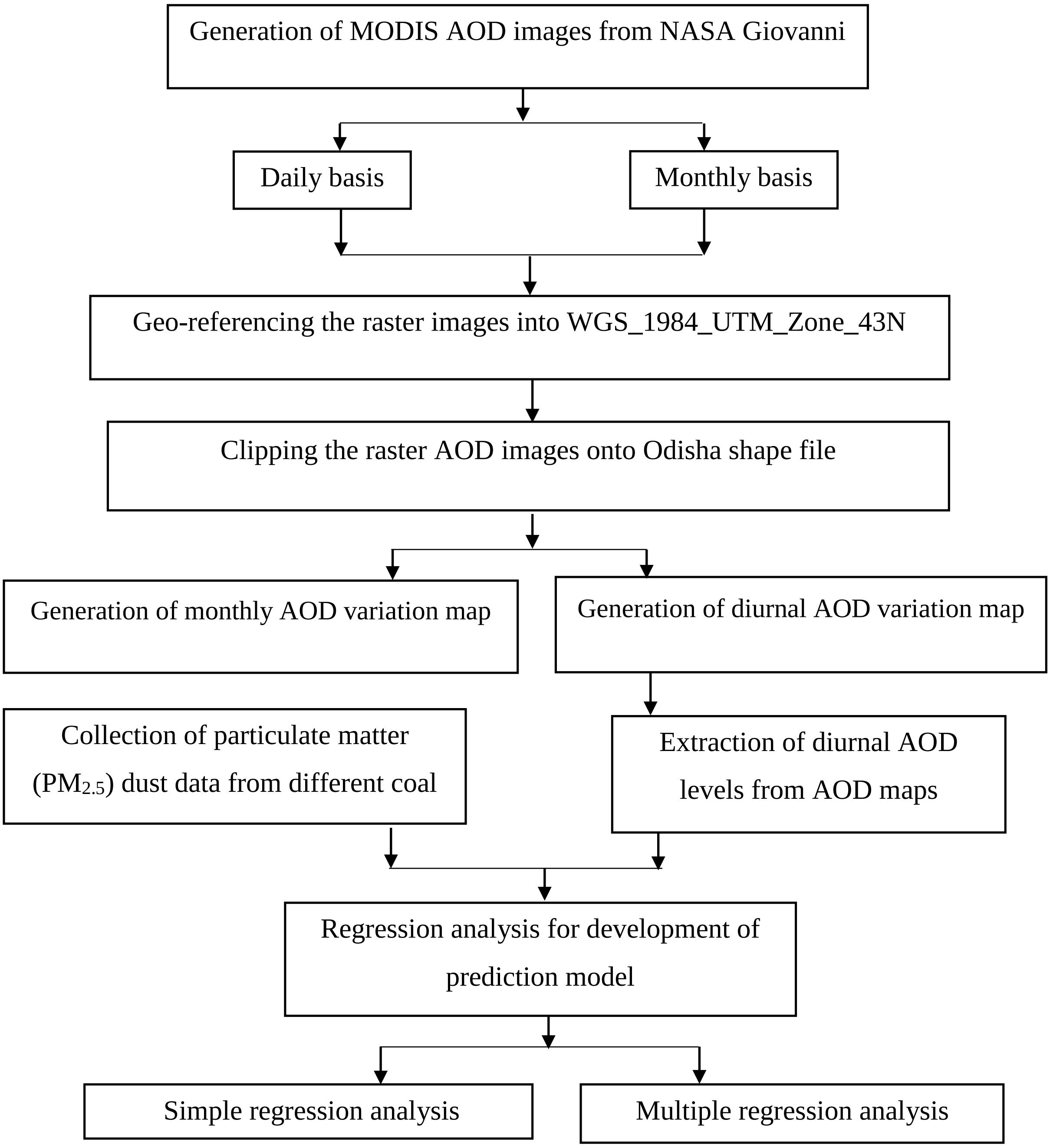



Figure 3.3: Flow chart showing the methodology followed in the research work

The AOD images were generated using Giovanni. The steps were:

MODIS Atmosphere Monthly Global Product and Daily Global Product were used for this study. They were retrieved from the source. The data used here were level 3 gridded products and belonged to collection 006. Product MYD08_M3 v6 was used for analysing monthly AOD variation, whereas MYD08_D3 v6 was used for diurnal AOD variation.

Step 1 The plot was selected to time averaged map.

Step 2 The desired area was selected by entering the longitude and latitude of the edges of your desired box as *West, South, East, North,* or click on the "Show Map" button and select an area with a click and drag movement.

Step 3 In the variable, discipline, measurement, Platform/Instrument, Spatial resolution, Temporal resolution were selected.

Step 4 The time period was selected.

Step 5 AOD maps were downloaded.

The downloaded AOD maps were geo-referenced and projected using ArcGIS to WGS_1984_UTM_Zone_43N coordinate system. Then they were clipped to the Odisha state shape file and then final AOD maps were generated.

The monthly AOD maps were generated for the time period April 2014 to May 2015 to study the seasonal AOD variation in the state. The diurnal AOD maps were generated for three months starting from $1^{st}$ April 2014 to $25^{th}$ June 2014 to study the daily AOD variation and its relation with particulate matter concentration. For this regression analysis was performed to develop the prediction model. It was done for three $PM_{2.5}$ monitoring station. The mean daily concentration of $PM_{2.5}$ was obtained in terms of $\mu g/m^3$. Linear regression analysis (both simple and multiple) were then performed by taking $PM_{2.5}$ concentration, MODIS AOD value, and meteorological parameter value for development of prediction model. Simple regressions were performed between PM concentration and AOD level. Multiple regressions were conducted using PM concentration, MODIS AOD value, and meteorological parameters (temperature, relative humidity, wind speed, solar radiation and precipitation).

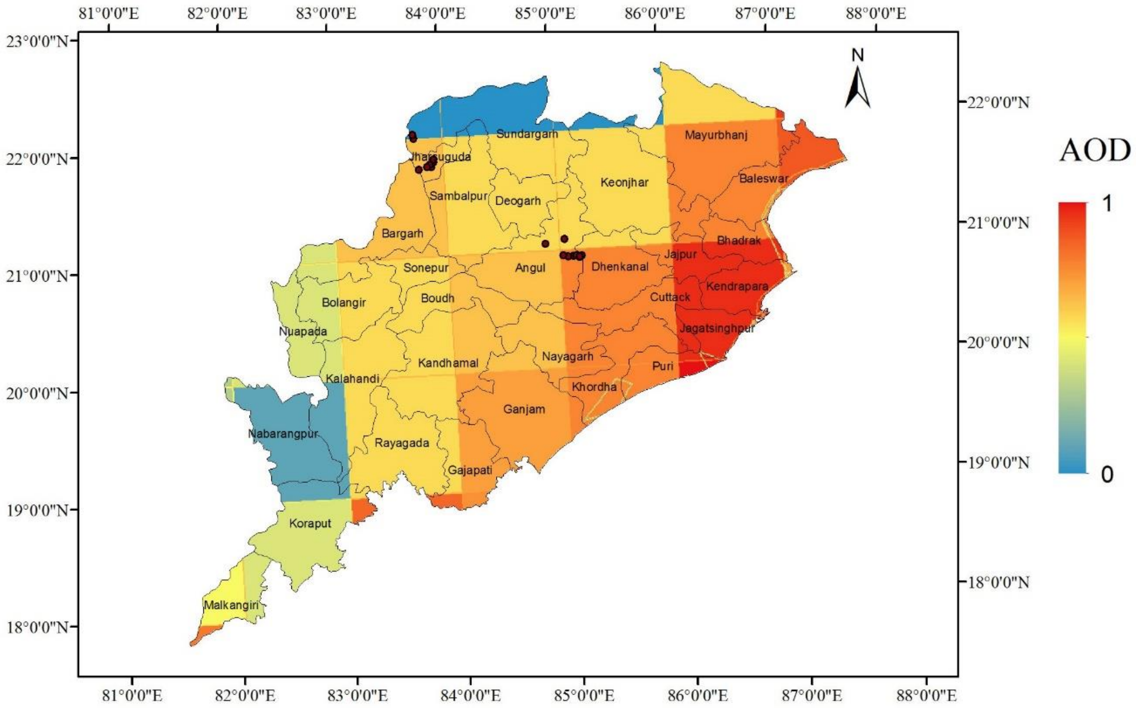
# Chapter 4

# Result and discussion

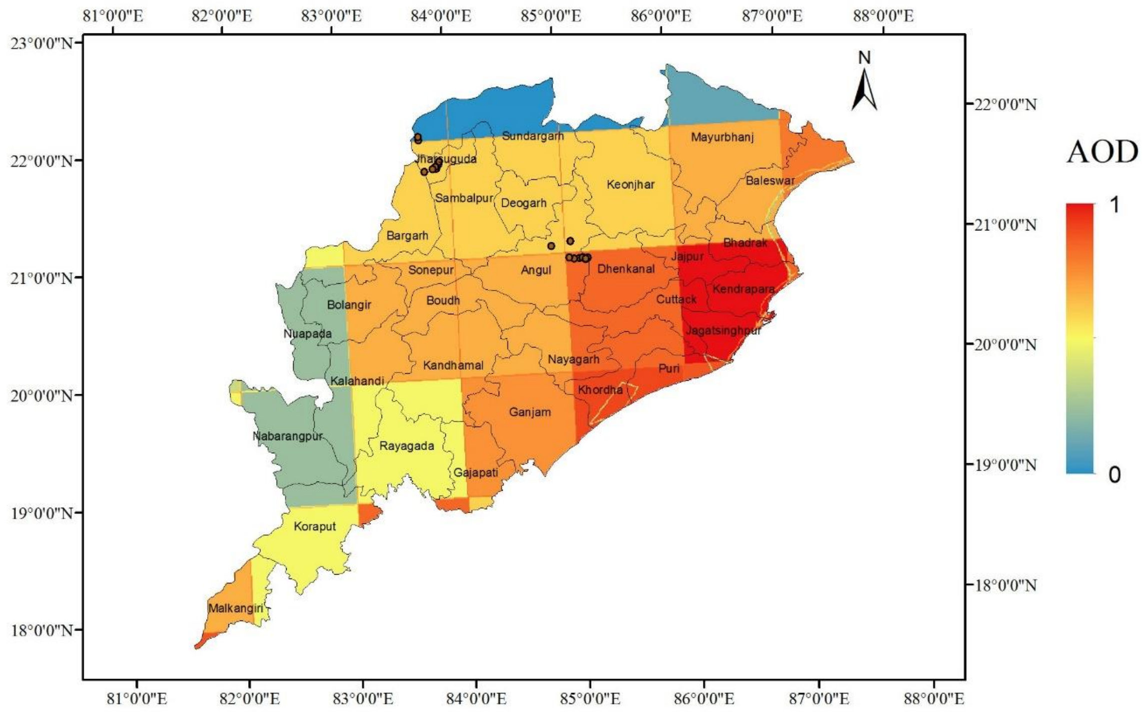
## 4.1 Seasonal/monthly AOD variations

The monthly AOD level of MODIS Aqua satellite over the state Odisha were shown in the Figure 4.1 (a-l) for duration of one year from April 2014 to May 2015.

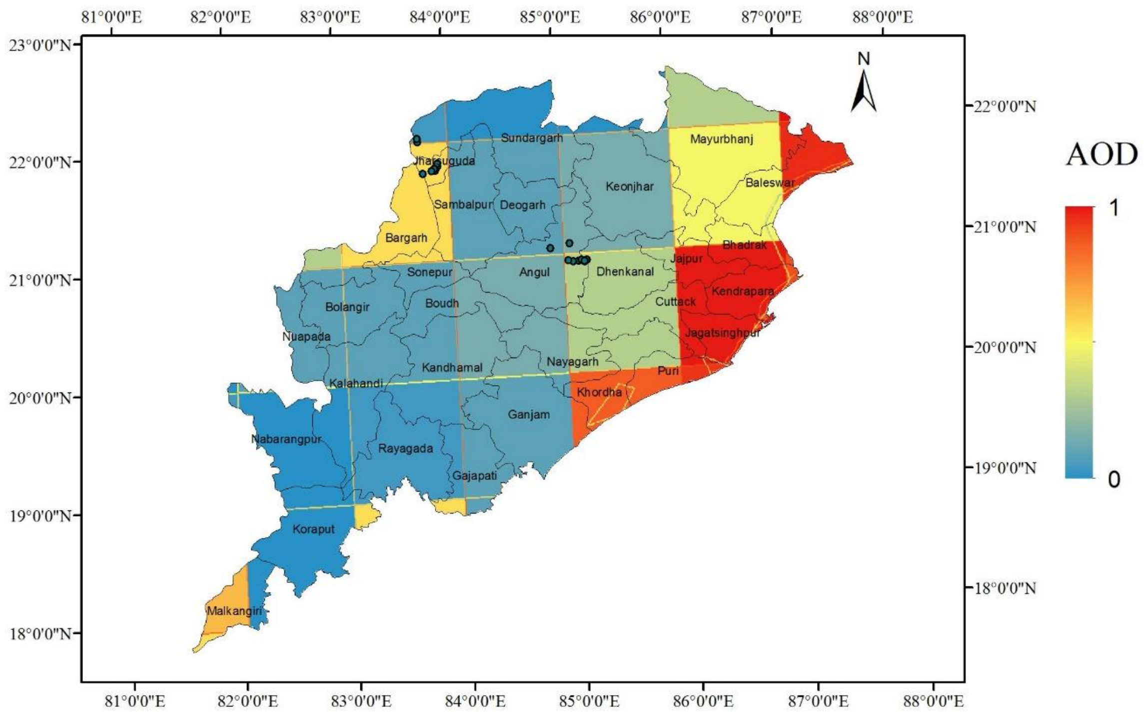
The maps below shows the AOD variation over the state in $1^0$ by $1^0$ pixel. The pixel are differentiated by different colour combination and the dotted spot in the maps are the coal mines area in the state. They are in Sundargarh, Jharsuguda, and Angul district.



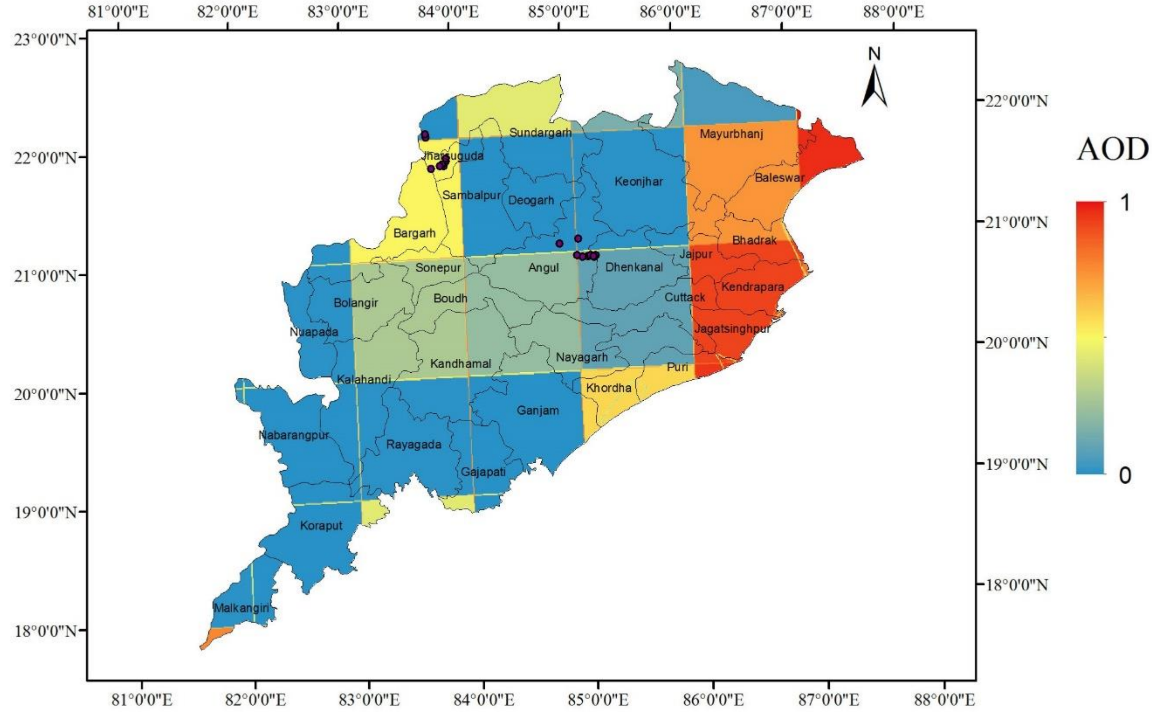

(a) April, 2014



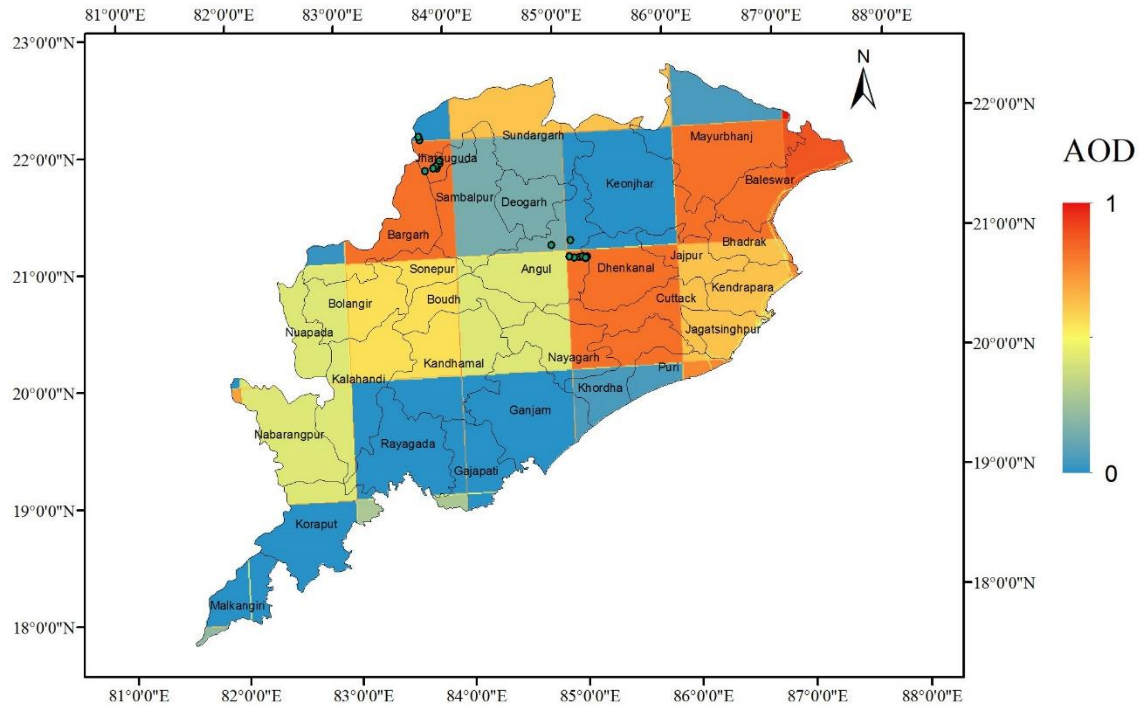

(b) May, 2014



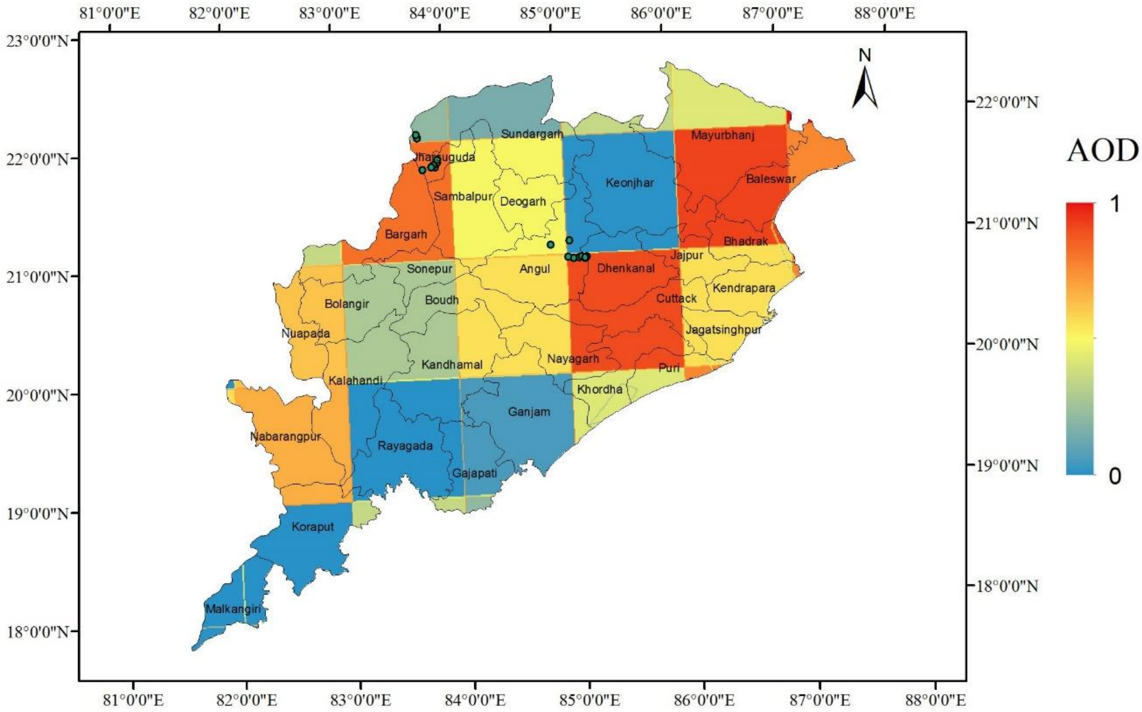

(c) June, 2014



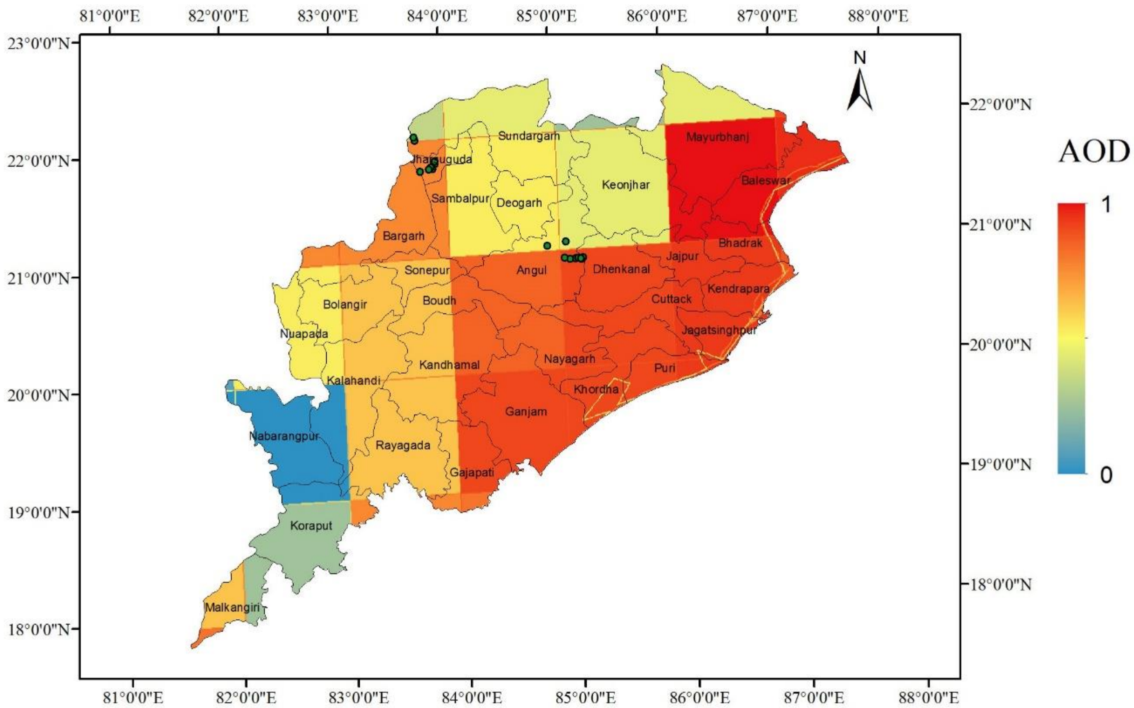

(d) July, 2014



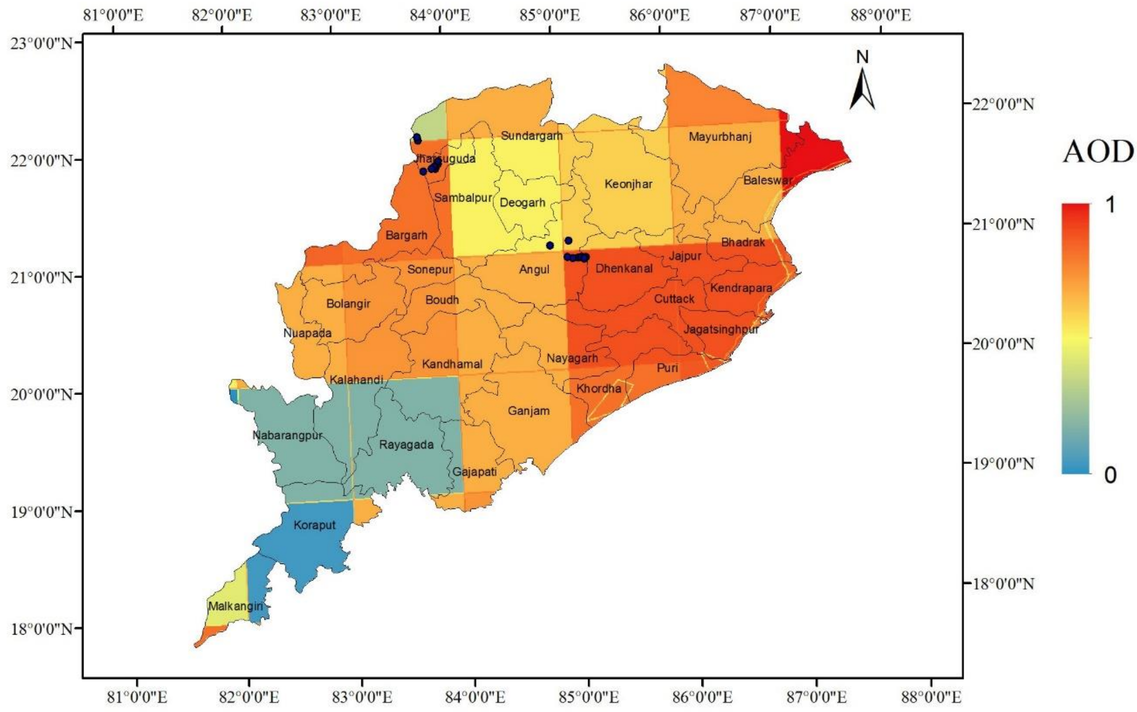

(e) August, 2014



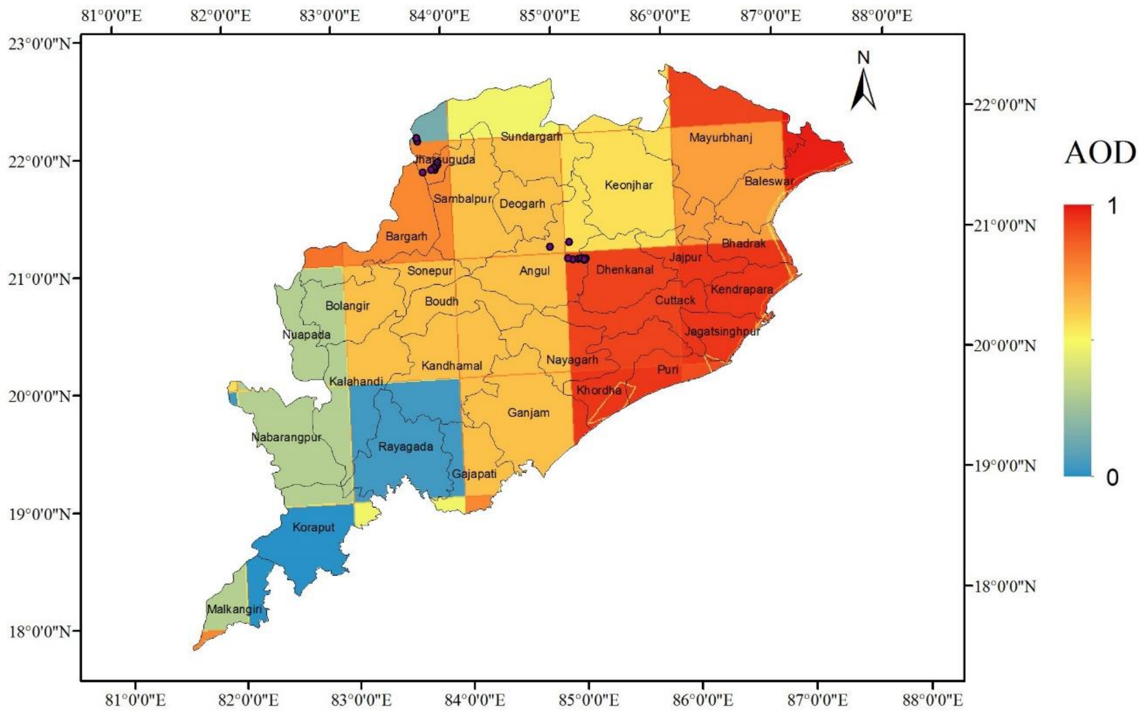

(f) September, 2014



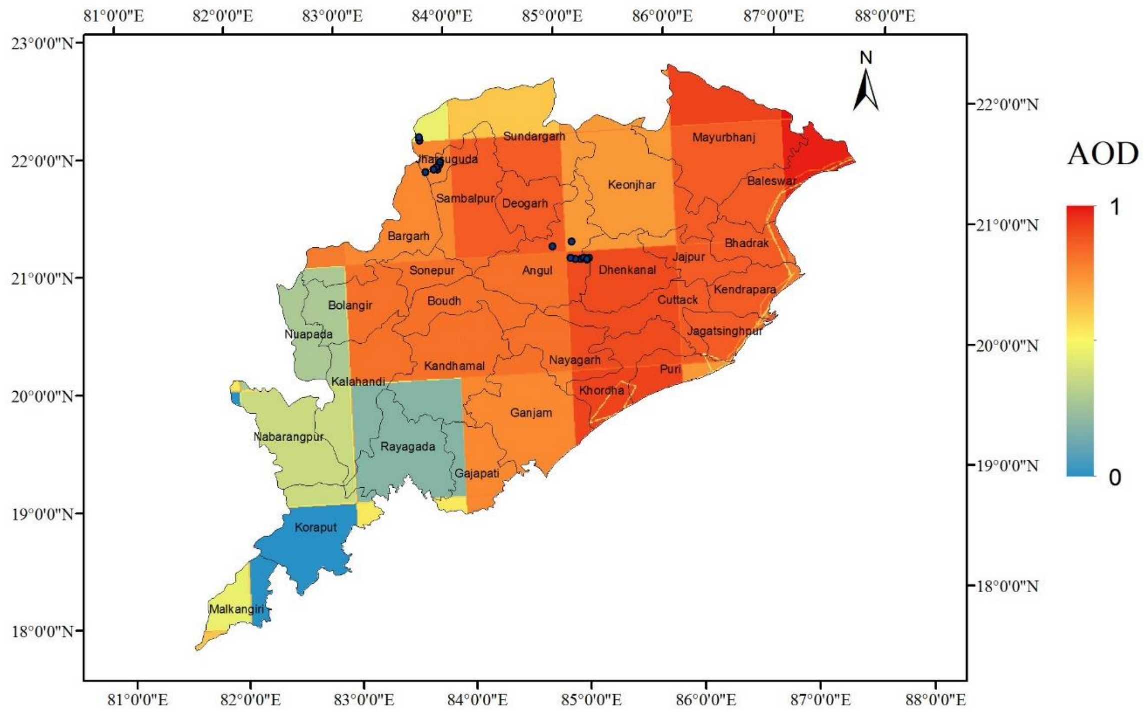

(g) October, 2014



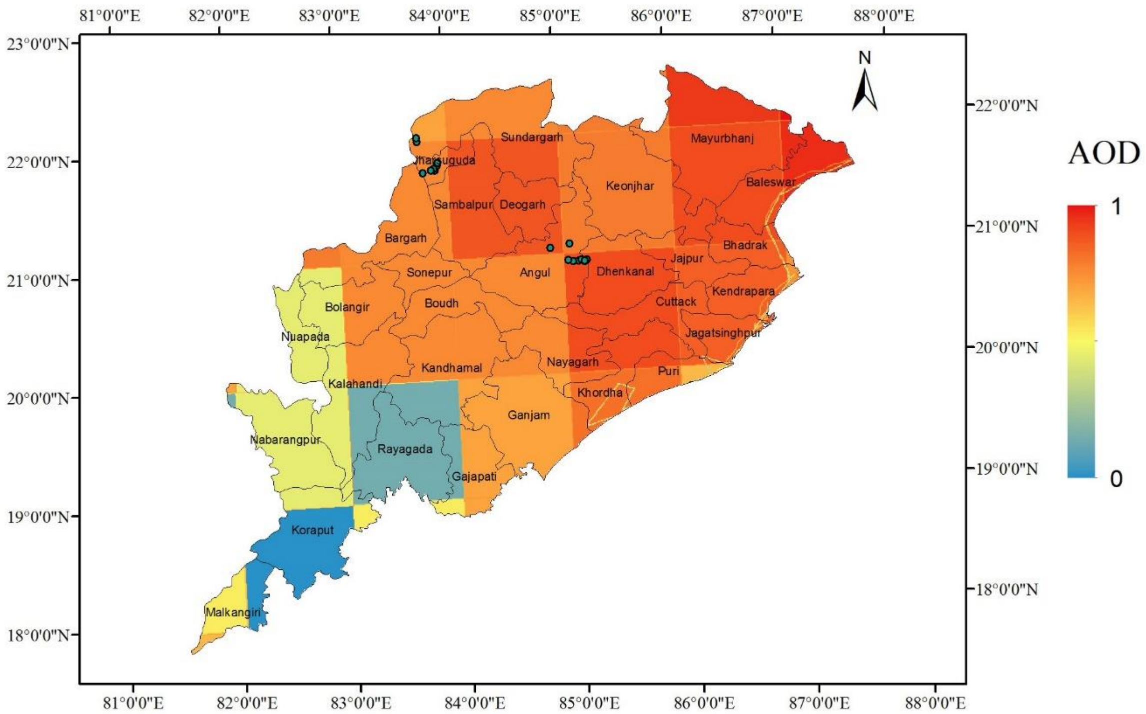

(h) November, 2014



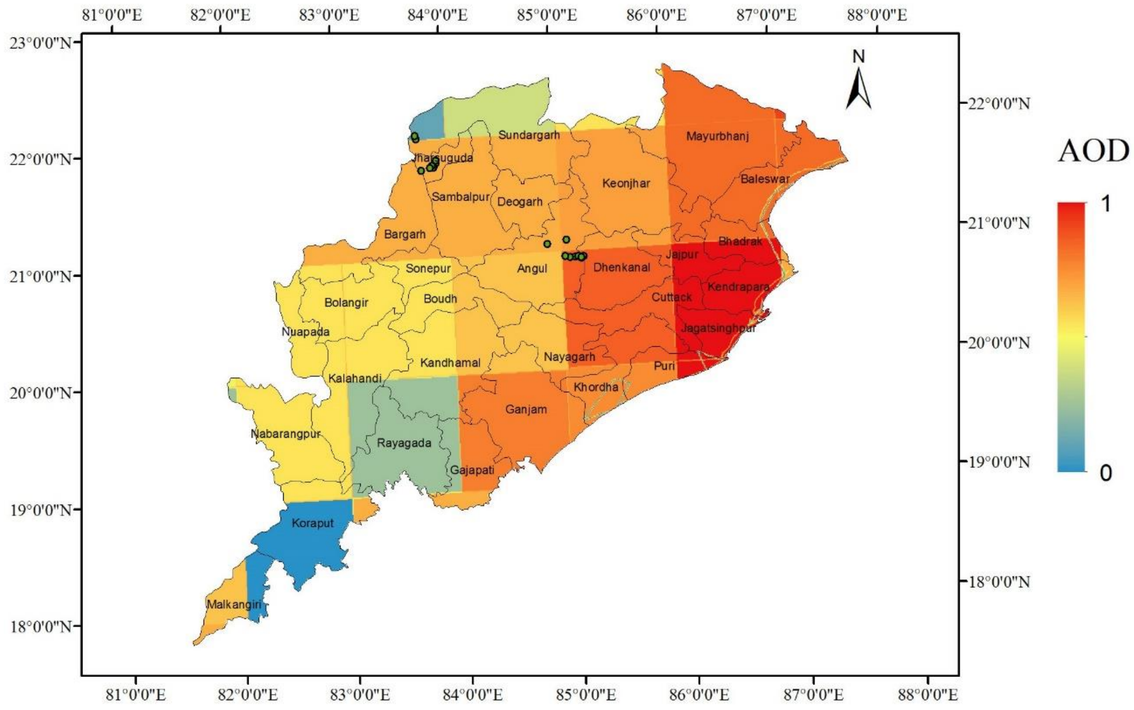

(i) December, 2014




(j) January, 2015




(k) February, 2015




(l) March, 2015

Figure 4.1: (a)-(l) Monthly average AOD profile maps

(a) April 2014, (b) May 2014, (c) June 2014, (d) July 2014, (e) August 2014, (f) September 2014, (g) October 2014, (h) November 2015, (i) December 2015, (j) January 2015, (k) February 2015, (l) March 2015

The state is mainly dominated by three seasons (summer, rainy, and winter). The summer season starts in the month of March and ends up to June. The rainy Season mainly of the months of July, August, and September and the months of October, November, December,January, and February are winter season. The seasonal AOD distribution maps of Odisha showed the AOD level distribution all over the state.

Odisha has a coastline along the Bay of Bengal to its east, from Balasore to Brahmapur district. Due to sea, there is high amount of sea salt aerosol. The sea salt aerosol comes from the sea spray. Thus, in the coastline area of the state showed a relatively high amount of aerosol throughout the year.  It can be observed from the maps that, AOD level in the rainy season is comparitively low as compared to summer and winter. In month of January and February the AOD level in all districts of the state expect the south part was more than 0.8. In months of June and july the AOD level was less than 0.4 in allmost every part of the state expect the coastal line area. The pre-monsoon months March, April, May showed AOD cencentration more than 0.5 in all part and in seashore area it was more than 0.8. The southern part of the state (Koraput, Malkangiri, Nabrangpur) showed a less amount of aerosol concentration throughout the year.

The coal mines areas are located in Angul, Jharsuguda, and sundargarh district. It can be seen from the data that, there is no significant effects of PM related air pollution to AOD level. But it can be observed from the maps that the industrial area of the state has always the AOD level moderate to high throughout the year expect in rainy season.

## 4.2 Diurnal AOD variation

The diurnal AOD level were extracted from AOD maps for three months (April 2014 to June 2014). The data were extracted for the same locations coincidence to PM measuring station of coal mines area. Due to low resolution of pixel, the AOD values are extracted for Ib valley coalfields taking Basundhara area in one zone (Zone 1) and Ib valley area, Lakhanpur area, and Orient area in other zone (Zone 2) and. Similarly, for Talcher coalfields the mine areas are taken in three zones. Chedipada OCP in zone1, Kaniha OCP in zone 2 and Balaram area, Jaganath area, Lingaraj area, and Talcher area in zone 3.

Figure 4.2 and Figure 4.3 showed the daily AOD variation of MODIS AOD level of Talcher coalfields and Ib valley coal coalfields respectively. Table 4.1 showed the diurnal AOD data of Talcher coal fields and Ib valley coalfields.

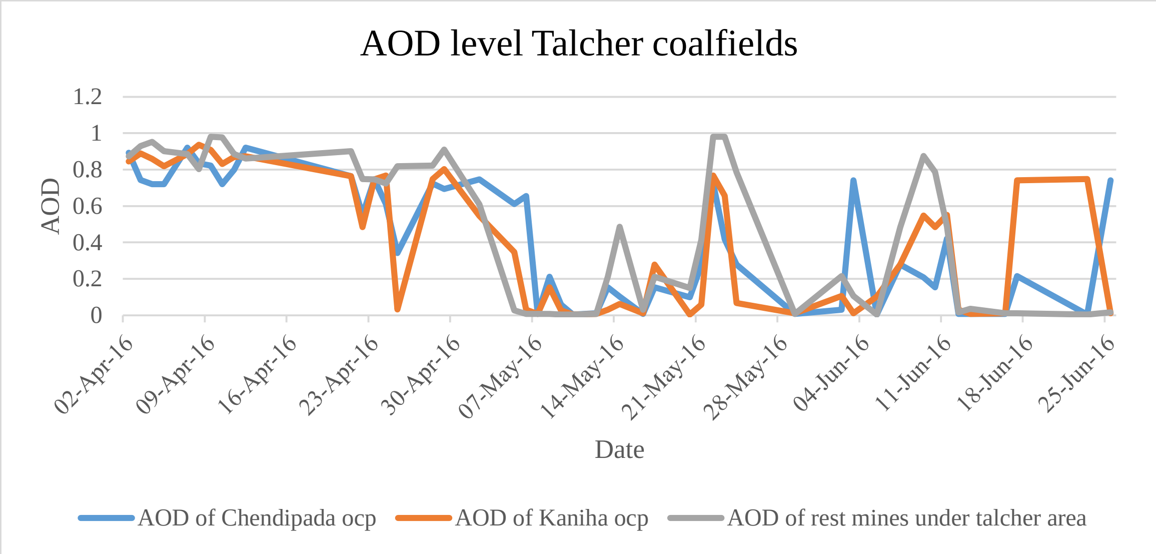



Figure 4.2: AOD level Talcher coalfields

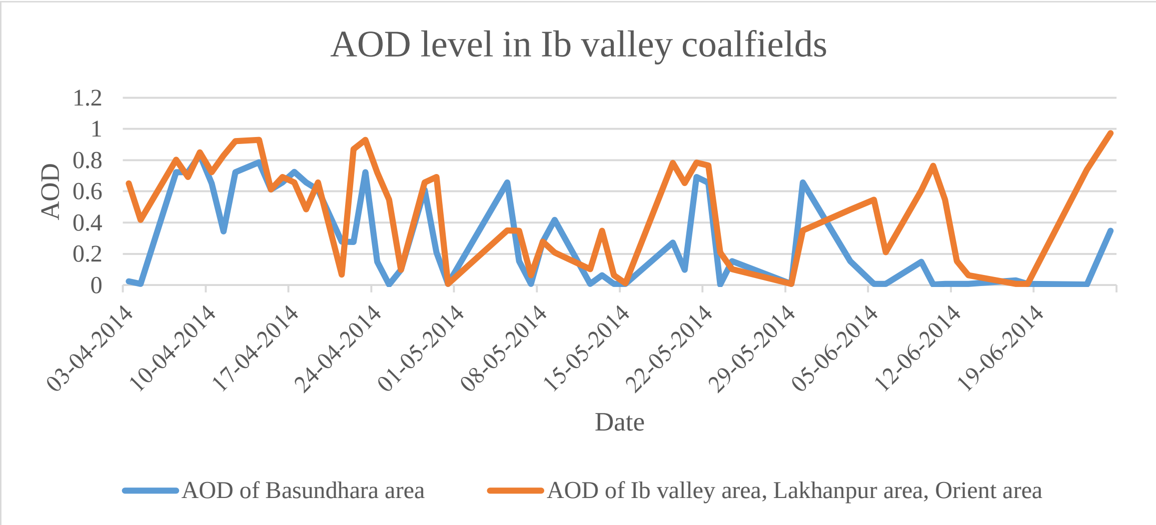



Figure 4.3: AOD level of IB valley coalfields

Table 4.1: MODSI AOD data of Talcher and Ib valley coalfields

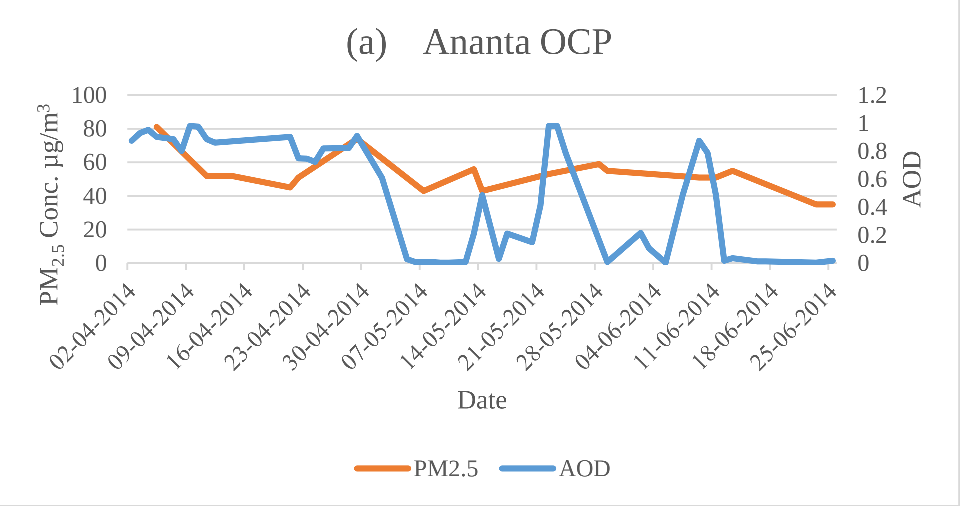
| | Ib valley coalfields | | Talcher coalfields | | |
|---|---|---|---|---|---|
| Date | Zone 1 | Zone 2 | Zone 1 | Zone 2 | Zone 3 |
| 01-04-2014 | NA | NA | NA | NA | NA |
| 02-04-2014 | NA | NA | 0.89328 | 0.84585 | 0.87352 |
| 03-04-2014 | 0.02372 | 0.65217 | 0.74308 | 0.88933 | 0.92885 |
| 04-04-2014 | 0.00787 | 0.41732 | 0.72047 | 0.85827 | 0.95276 |
| 05-04-2014 | NA | NA | 0.72047 | 0.8189 | 0.90157 |
| 06-04-2014 | NA | NA | NA | NA | NA |
| 07-04-2014 | 0.72332 | 0.80237 | 0.92095 | 0.88538 | 0.88538 |
| 08-04-2014 | 0.72332 | 0.6917 | 0.83399 | 0.93676 | 0.80237 |
| 09-04-2014 | 0.83399 | 0.8498 | 0.82213 | 0.90909 | 0.98024 |
| 10-04-2014 | 0.65217 | 0.72332 | 0.71937 | 0.83004 | 0.97628 |
| 11-04-2014 | 0.34387 | 0.83004 | 0.79842 | 0.86957 | 0.88538 |
| 12-04-2014 | 0.72332 | 0.92095 | 0.92095 | 0.87352 | 0.86166 |
| 13-04-2014 | NA | NA | NA | NA | NA |
| 14-04-2014 | 0.78656 | 0.92885 | NA | NA | NA |
| 15-04-2014 | 0.61176 | 0.61176 | NA | NA | NA |
| 16-04-2014 | 0.65748 | 0.69291 | NA | NA | NA |
| 17-04-2014 | 0.72441 | 0.65748 | NA | NA | NA |
| 18-04-2014 | 0.65748 | 0.48425 | NA | NA | NA |
| 19-04-2014 | 0.61024 | 0.65748 | NA | NA | NA |
| 20-04-2014 | NA | NA | NA | NA | NA |
| 21-04-2014 | 0.27843 | 0.06667 | 0.76471 | 0.76471 | 0.90196 |
| 22-04-2014 | 0.27559 | 0.87008 | 0.55118 | 0.48425 | 0.74803 |
| 23-04-2014 | 0.72332 | 0.92885 | 0.74704 | 0.74704 | 0.74704 |
| 24-04-2014 | 0.14961 | 0.72047 | 0.61024 | 0.76772 | 0.72441 |
| 25-04-2014 | 0.00394 | 0.54724 | 0.34252 | 0.0315 | 0.8189 |
| 26-04-2014 | 0.09843 | 0.09843 | NA | NA | NA |
| 27-04-2014 | NA | NA | NA | NA | NA |
| 28-04-2014 | 0.61024 | 0.65748 | 0.72441 | 0.74803 | 0.82283 |

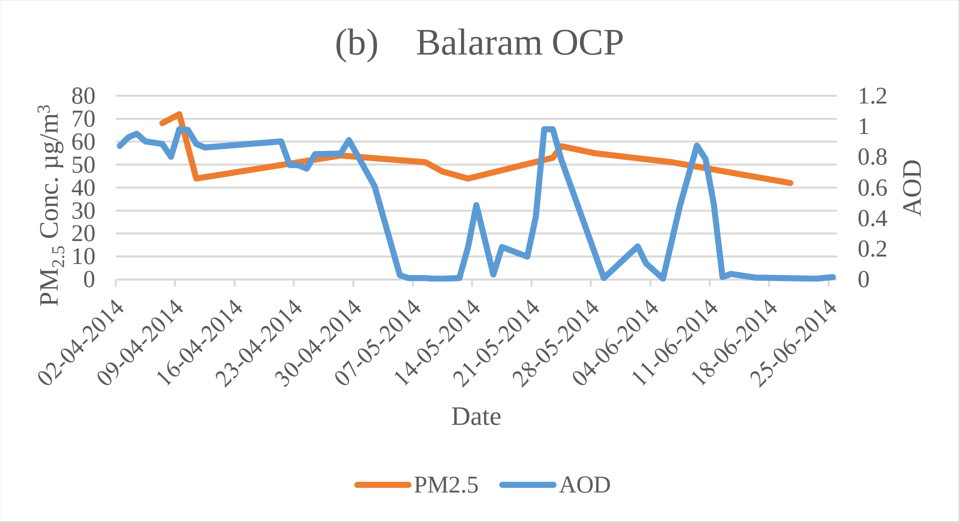
| | | | | | |
|---|---|---|---|---|---|
| 29-04-2014 | 0.20866 | 0.69291 | 0.69291 | 0.80315 | 0.90945 |
| 30-04-2014 | 0.00784 | 0.00784 | NA | NA | NA |
| 01-05-2014 | NA | NA | NA | NA | NA |
| 02-05-2014 | NA | NA | 0.74704 | 0.54545 | 0.6087 |
| 03-05-2014 | NA | NA | NA | NA | NA |
| 04-05-2014 | NA | NA | NA | NA | NA |
| 05-05-2014 | 0.65748 | 0.35039 | 0.61024 | 0.34646 | 0.02756 |
| 06-05-2014 | 0.15294 | 0.34902 | 0.6549 | 0.03137 | 0.00784 |
| 07-05-2014 | 0.00784 | 0.06275 | 0.00784 | 0.00784 | 0.00784 |
| 08-05-2014 | 0.27843 | 0.27843 | 0.21176 | 0.15294 | 0.00784 |
| 09-05-2014 | 0.41732 | 0.20866 | 0.05906 | 0.02756 | 0.00394 |
| 10-05-2014 | NA | NA | 0.00394 | 0.00394 | 0.00394 |
| 11-05-2014 | NA | NA | NA | NA | NA |
| 12-05-2014 | 0.00784 | 0.10196 | 0.01176 | 0.00784 | 0.00784 |
| 13-05-2014 | 0.06275 | 0.34902 | 0.15294 | 0.03137 | 0.21176 |
| 14-05-2014 | 0.00784 | 0.06275 | 0.10196 | 0.06275 | 0.48627 |
| 15-05-2014 | 0.00784 | 0.01176 | NA | NA | NA |
| 16-05-2014 | NA | NA | 0.00784 | 0.01176 | 0.03137 |
| 17-05-2014 | NA | NA | 0.15294 | 0.27843 | 0.21176 |
| 18-05-2014 | NA | NA | NA | NA | NA |
| 19-05-2014 | 0.27273 | 0.78261 | NA | NA | NA |
| 20-05-2014 | 0.09843 | 0.65354 | 0.09843 | 0.00394 | 0.14961 |
| 21-05-2014 | 0.69291 | 0.78346 | 0.27559 | 0.05906 | 0.41339 |
| 22-05-2014 | 0.65613 | 0.7668 | 0.72332 | 0.7668 | 0.98024 |
| 23-05-2014 | 0.00394 | 0.20866 | 0.41732 | 0.65748 | 0.98031 |
| 24-05-2014 | 0.15294 | 0.10196 | 0.27843 | 0.06667 | 0.78431 |
| 25-05-2014 | NA | NA | NA | NA | NA |
| 26-05-2014 | NA | NA | NA | NA | NA |
| 27-05-2014 | NA | NA | NA | NA | NA |
| 28-05-2014 | NA | NA | NA | NA | NA |
| 29-05-2014 | 0.00784 | 0.00784 | 0.00784 | 0.01176 | 0.00784 |

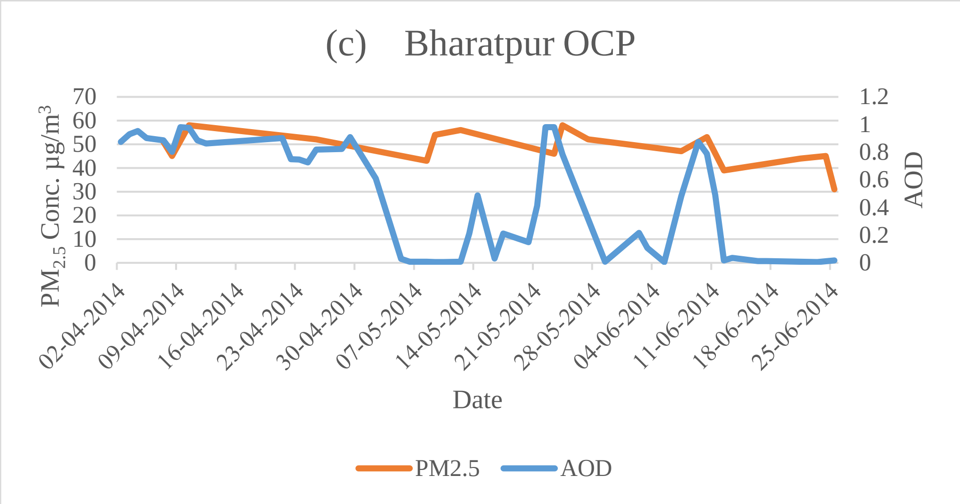
| | | | | | |
|---|---|---|---|---|---|
| 30-05-2014 | 0.65748 | 0.35039 | NA | NA | NA |
| 31-05-2014 | NA | NA | NA | NA | NA |
| 01-06-2014 | NA | NA | NA | NA | NA |
| 02-06-2014 | NA | NA | 0.03137 | 0.10588 | 0.21569 |
| 03-06-2014 | 0.15294 | 0.48235 | 0.74118 | 0.01176 | 0.10588 |
| 04-06-2014 | NA | NA | NA | NA | NA |
| 05-06-2014 | 0.00787 | 0.54724 | 0.00394 | 0.10236 | 0.00394 |
| 06-06-2014 | 0.00784 | 0.21176 | NA | NA | NA |
| 07-06-2014 | NA | NA | 0.27843 | 0.27843 | 0.48235 |
| 08-06-2014 | NA | NA | NA | NA | NA |
| 09-06-2014 | 0.14961 | 0.6063 | 0.20866 | 0.54724 | 0.87402 |
| 10-06-2014 | 0.00394 | 0.76378 | 0.15354 | 0.48425 | 0.7874 |
| 11-06-2014 | 0.00787 | 0.54724 | 0.42126 | 0.55118 | 0.48819 |
| 12-06-2014 | 0.00784 | 0.15294 | 0.00784 | 0.03137 | 0.01569 |
| 13-06-2014 | 0.00784 | 0.06275 | 0.00784 | 0.00784 | 0.03529 |
| 14-06-2014 | NA | NA | NA | NA | NA |
| 15-06-2014 | NA | NA | NA | NA | NA |
| 16-06-2014 | NA | NA | 0.00784 | 0.01176 | 0.01176 |
| 17-06-2014 | 0.03137 | 0.00784 | 0.21569 | 0.74118 | 0.01176 |
| 18-06-2014 | 0.00784 | 0.00784 | NA | NA | NA |
| 19-06-2014 | NA | NA | NA | NA | NA |
| 20-06-2014 | NA | NA | NA | NA | NA |
| 21-06-2014 | NA | NA | NA | NA | NA |
| 22-06-2014 | NA | NA | NA | NA | NA |
| 23-06-2014 | 0.00394 | 0.74016 | 0.00394 | 0.74803 | 0.00394 |
| 24-06-2014 | NA | NA | NA | NA | NA |
| 25-06-2014 | 0.34902 | 0.97255 | 0.74118 | 0.01176 | 0.01569 |

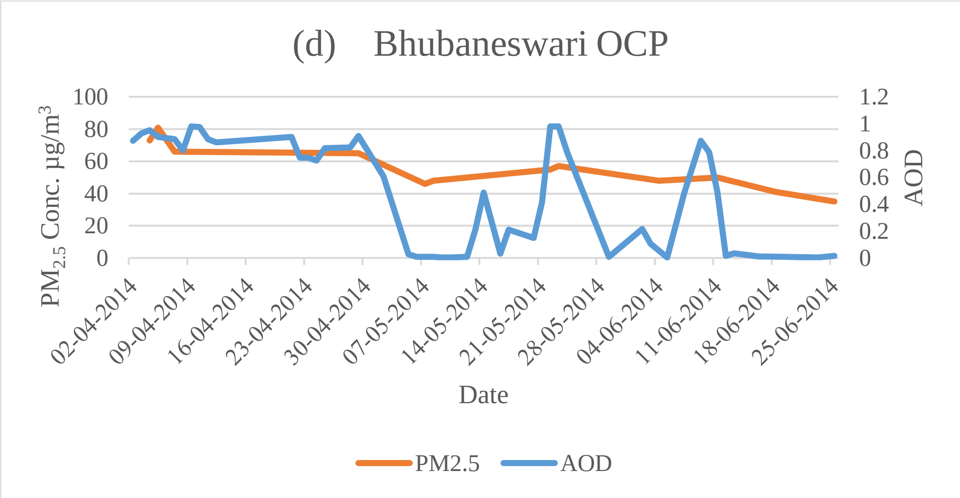
### 4.2.1 Comparison of diurnal average MODIS AOD level data with ground level $PM_{2.5}$ data

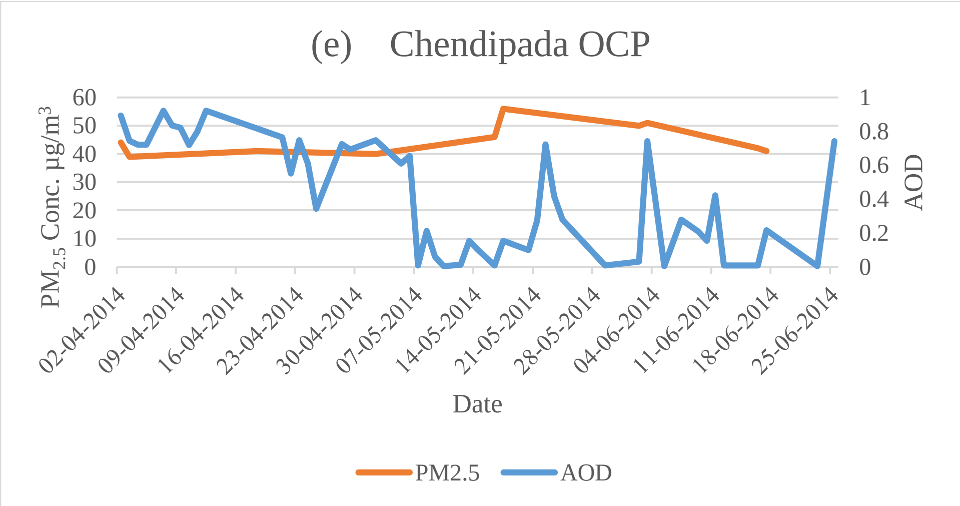
The daily average $PM_{2.5}$ data of different coal fields of MCL were compared with MODIS diurnal AOD level data collected from the same location. The graphs between MODIS AOD and $PM_{2.5}$ of different coal fields were shown in the Figure 4.1 (a-f).

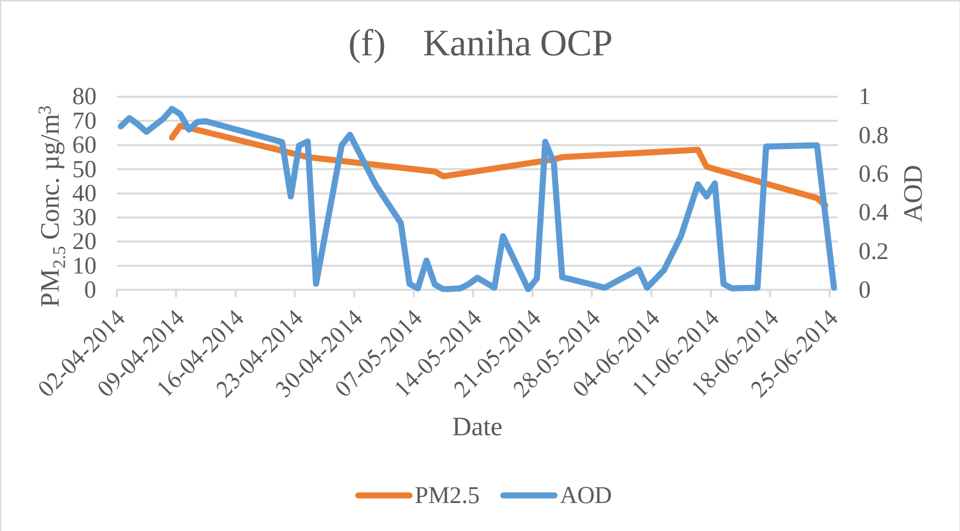


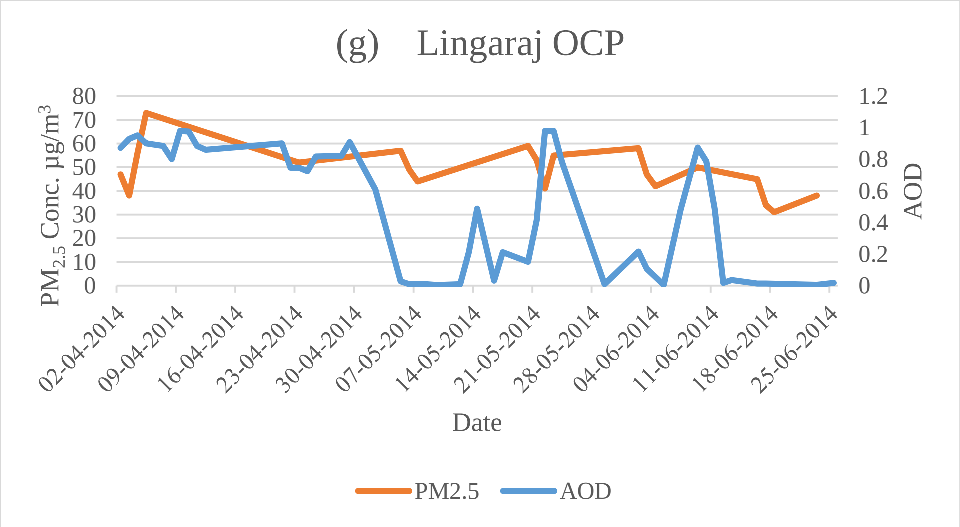

(c) Bharatpur OCP
PM2.5 Conc. µg/m3
70
60
50
40
30
20
10
0
1.2
1
0.8
0.6
0.4
0.2
0
AOD
02-04-2014
09-04-2014
16-04-2014
23-04-2014
30-04-2014
07-05-2014
14-05-2014
21-05-2014
28-05-2014
04-06-2014
11-06-2014
18-06-2014
25-06-2014
Date
PM2.5
AOD


(d) Bhubaneswari OCP
PM2.5 Conc. µg/m3
100
80
60
40
20
0
1.2
1
0.8
0.6
0.4
0.2
0
AOD
02-04-2014
09-04-2014
16-04-2014
23-04-2014
30-04-2014
07-05-2014
14-05-2014
21-05-2014
28-05-2014
04-06-2014
11-06-2014
18-06-2014
25-06-2014
Date
PM2.5
AOD

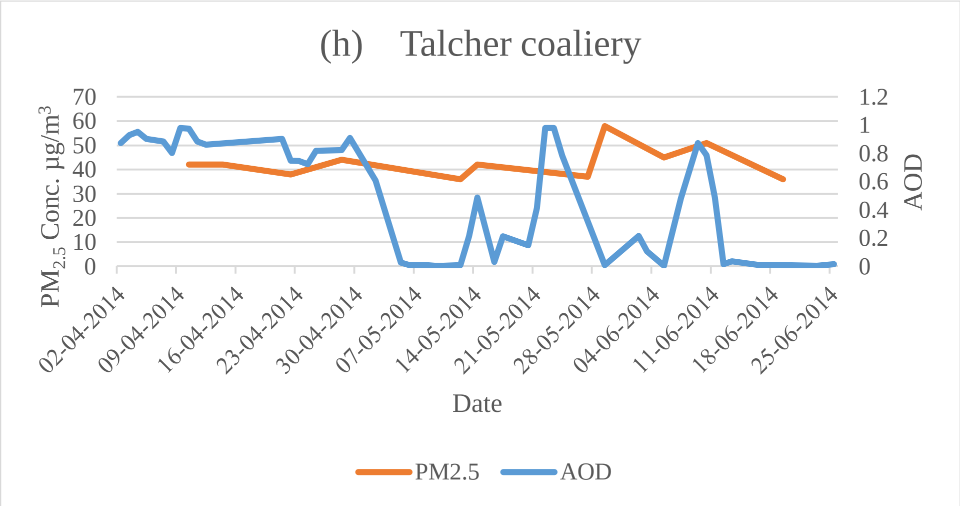

(e) Chendipada OCP
PM2.5 Conc. µg/m3
60
50
40
30
20
10
0
1
0.8
0.6
0.4
0.2
0
AOD
02-04-2014
09-04-2014
16-04-2014
23-04-2014
30-04-2014
07-05-2014
14-05-2014
21-05-2014
28-05-2014
04-06-2014
11-06-2014
18-06-2014
25-06-2014
Date
PM2.5
AOD



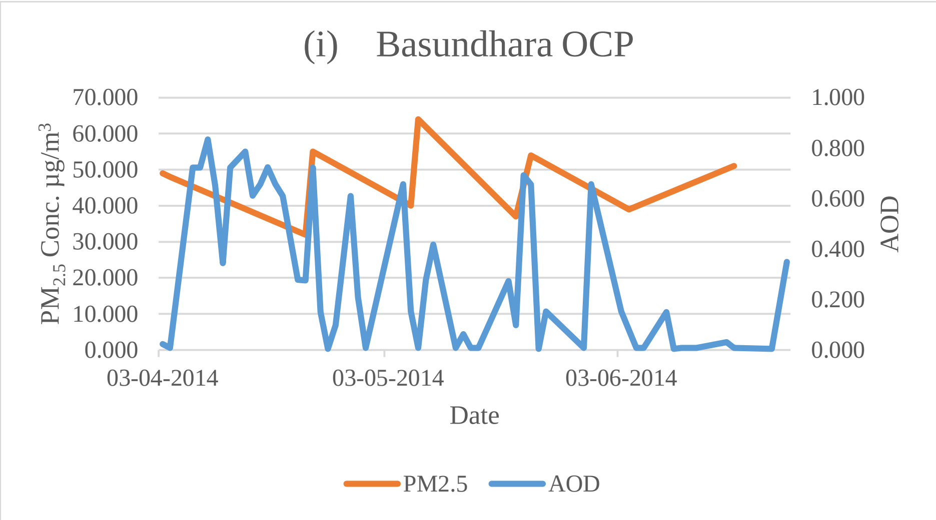
(f) Kaniha OCP
PM2.5 Conc. µg/m3
80
70
60
50
40
30
20
10
0
1
0.8
0.6
0.4
0.2
0
AOD
02-04-2014
09-04-2014
16-04-2014
23-04-2014
30-04-2014
07-05-2014
14-05-2014
21-05-2014
28-05-2014
04-06-2014
11-06-2014
18-06-2014
25-06-2014
Date
PM2.5
AOD

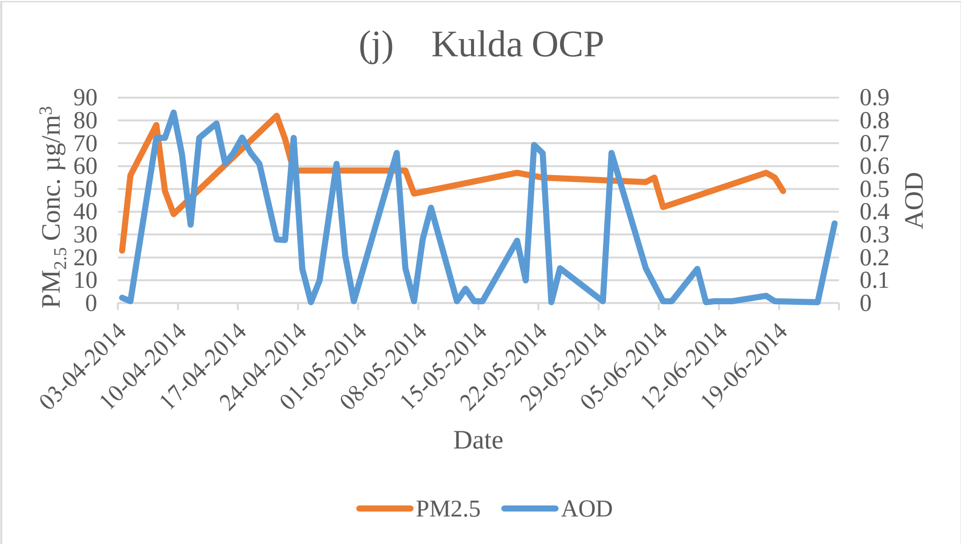



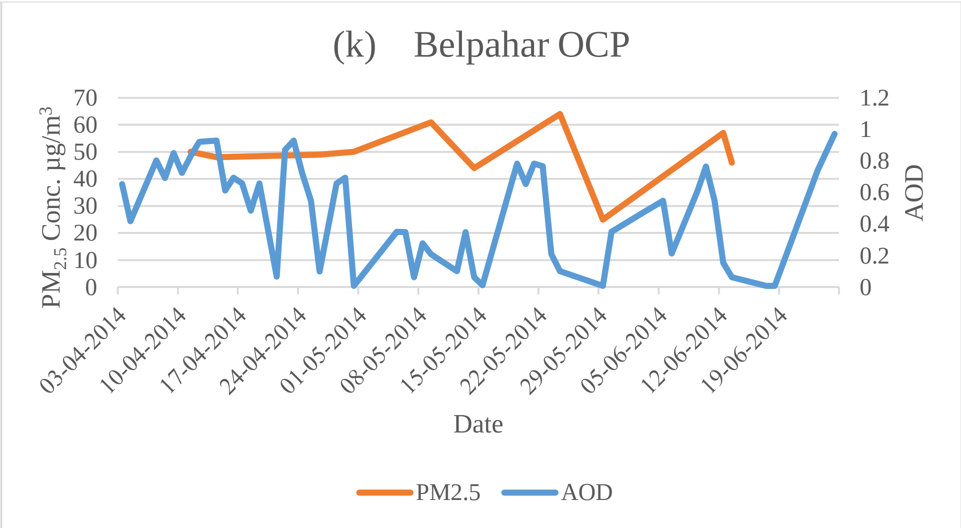
(g) Lingaraj OCP
PM2.5 Conc. µg/m3
80
70
60
50
40
30
20
10
0
1.2
1
0.8
0.6
0.4
0.2
0
AOD
02-04-2014
09-04-2014
16-04-2014
23-04-2014
30-04-2014
07-05-2014
14-05-2014
21-05-2014
28-05-2014
04-06-2014
11-06-2014
18-06-2014
25-06-2014
Date
PM2.5
AOD

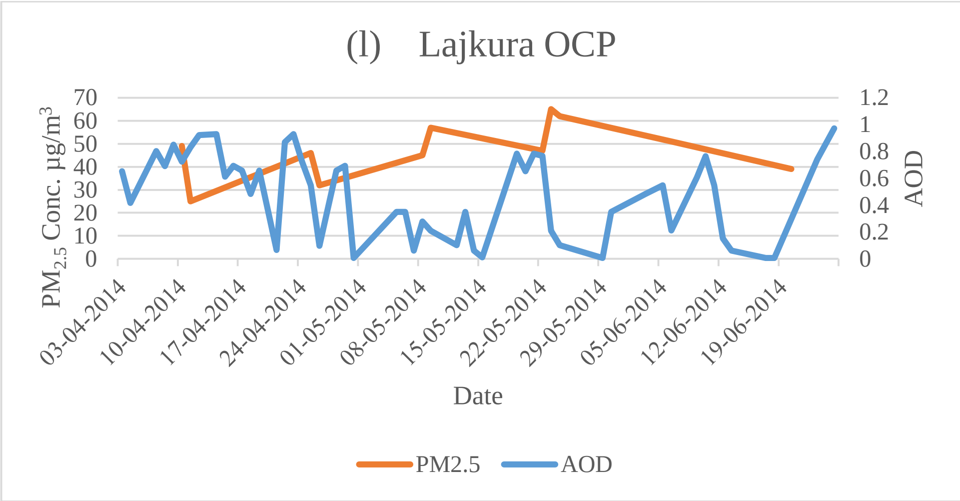



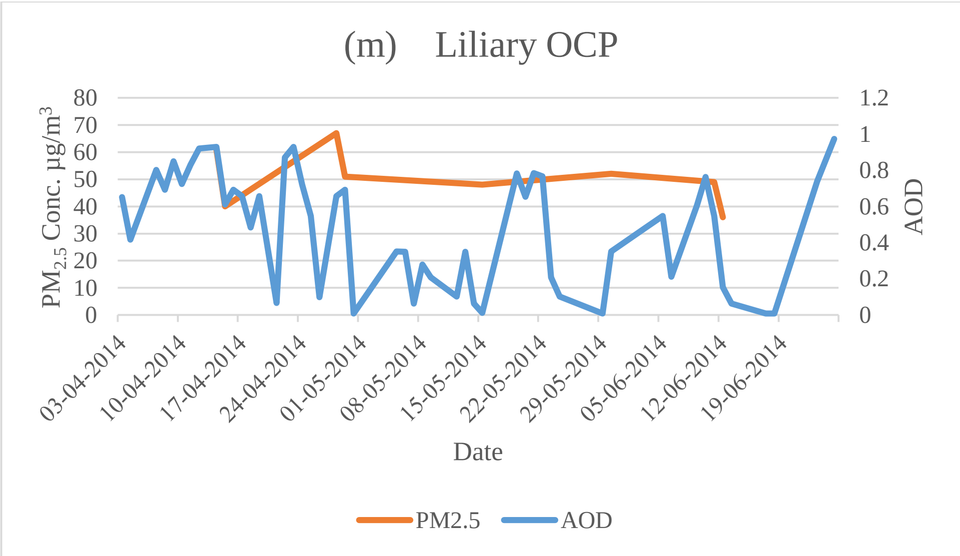
(h) Talcher coaliery
PM2.5 Conc. µg/m3
70
60
50
40
30
20
10
0
1.2
1
0.8
0.6
0.4
0.2
0
AOD
02-04-2014
09-04-2014
16-04-2014
23-04-2014
30-04-2014
07-05-2014
14-05-2014
21-05-2014
28-05-2014
04-06-2014
11-06-2014
18-06-2014
25-06-2014
Date
PM2.5
AOD

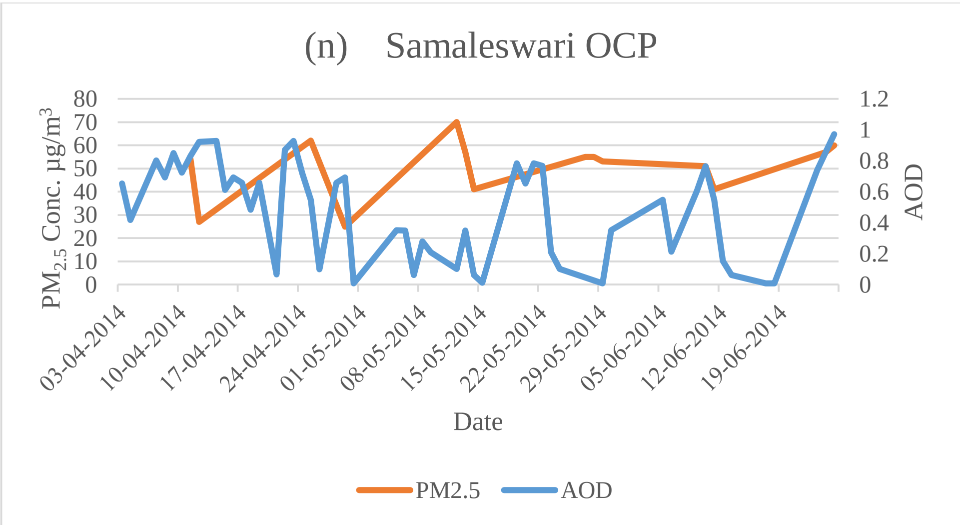

(i) Basundhara OCP
70.000
60.000
50.000
40.000
30.000
20.000
10.000
0.000
1.000
0.800
0.600
0.400
0.200
0.000
PM2.5 Conc. µg/m3
AOD
03-04-2014
03-05-2014
03-06-2014
Date
PM2.5
AOD

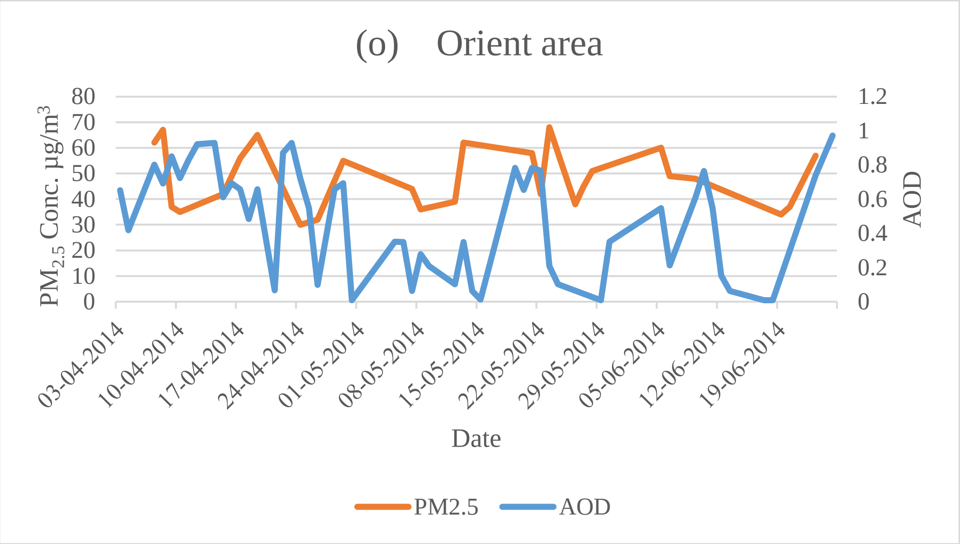

(j) Kulda OCP
90
80
70
60
50
40
30
20
10
0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
PM2.5 Conc. µg/m3
AOD
03-04-2014
10-04-2014
17-04-2014
24-04-2014
01-05-2014
08-05-2014
15-05-2014
22-05-2014
29-05-2014
05-06-2014
12-06-2014
19-06-2014
Date
PM2.5
AOD


(k) Belpahar OCP
70
60
50
40
30
20
10
0
1.2
1
0.8
0.6
0.4
0.2
0
PM2.5 Conc. µg/m3
AOD
03-04-2014
10-04-2014
17-04-2014
24-04-2014
01-05-2014
08-05-2014
15-05-2014
22-05-2014
29-05-2014
05-06-2014
12-06-2014
19-06-2014
Date
PM2.5
AOD


(l) Lajkura OCP
PM2.5 Conc. µg/m3
AOD
70
60
50
40
30
20
10
0
1.2
1
0.8
0.6
0.4
0.2
0
03-04-2014
10-04-2014
17-04-2014
24-04-2014
01-05-2014
08-05-2014
15-05-2014
22-05-2014
29-05-2014
05-06-2014
12-06-2014
19-06-2014
Date
PM2.5
AOD


(m) Liliary OCP
PM2.5 Conc. µg/m3
AOD
80
70
60
50
40
30
20
10
0
1.2
1
0.8
0.6
0.4
0.2
0
03-04-2014
10-04-2014
17-04-2014
24-04-2014
01-05-2014
08-05-2014
15-05-2014
22-05-2014
29-05-2014
05-06-2014
12-06-2014
19-06-2014
Date
PM2.5
AOD


(n) Samaleswari OCP
PM2.5 Conc. µg/m3
AOD
80
70
60
50
40
30
20
10
0
1.2
1
0.8
0.6
0.4
0.2
0
03-04-2014
10-04-2014
17-04-2014
24-04-2014
01-05-2014
08-05-2014
15-05-2014
22-05-2014
29-05-2014
05-06-2014
12-06-2014
19-06-2014
Date
PM2.5
AOD



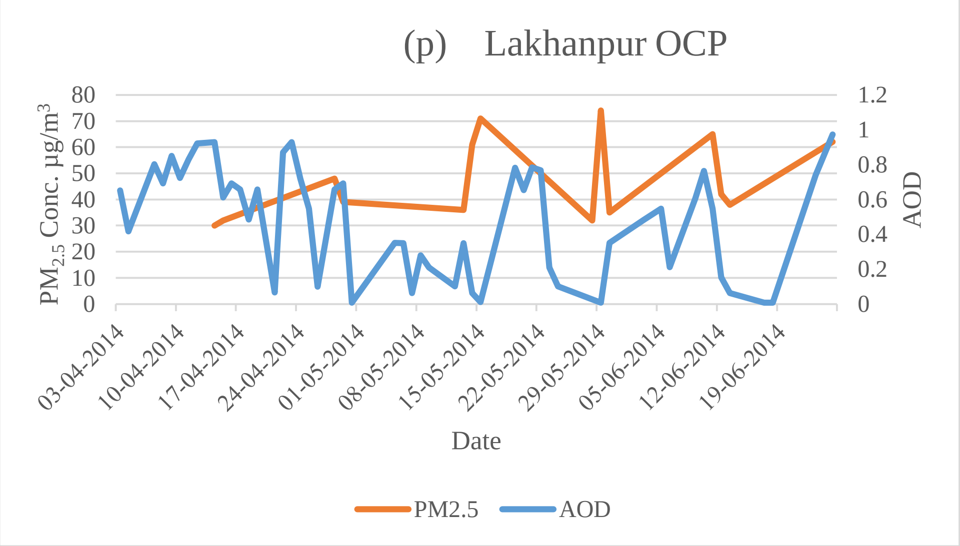




Figure 4.4: (a)-(p) Comparison of diurnal MODIS AOD and daily averaged $PM_{2.5}$

(a) Ananta OCP, (b) Balaram OCP, (c) Bharatpur OCP, (d) Bhubaneswari OCP, (e) Chendipada OCP, (f) Kaniha OCP, (g) Lingaraj OCP, (h) Talcher colliery, (i) Basundhara OCP, (j) Kulda OCP, (k) Belpahar OCP, (l) Lajkura OCP, (m) Liliary OCP, (n) Samaleswari OCP, (o) Orient area, (p) Lakhanpur OCP

# Chapter 5

# Regression analysis

## 5.1 Background

There is a significant relationship between exposure to fine particulate air pollution and health problems. The air quality is degrading day by day and becoming worse. Therefore, monitoring and control of air pollution are very much required. The traditional ground-based monitoring of particulate matter is more time consuming and restricted to a particular site only and in some of the area, there is no facility for monitoring. Thus, considering the high spatial and temporal variability of particulate matter, the traditional monitoring is quite difficult to cover the entire area seamlessly. On the other hand, satellite monitoring can able to provide information over the larger spatial domain. Thus, prediction of particulate matter from satellite data is much better option than the traditional approach of monitoring. The present study uses the MODIS AOD data for estimating the particulate matter concentration in mining areas. The study attempts to develop linear regression model for predicting the PM concentrations from AOD level.

## 5.2 Linear regression

Linear regression is a statistical approach that attempts to model the relationship between two variables by fitting a linear equation to observed data. Here one variable is considered as a dependent variable and one or more explanatory variable are considered as the independent variable. The case of one explanatory variable is known as simple linear regression and for more than one explanatory variable, the process is called multiple linear regression.

### 5.2.1 Simple linear regression

In the simple linear regression analyses, relationship between one dependent and one independent variable is examined. After performing the analyses, the regression statistics can be used to predict the dependent variable based on the known independent variable.

Mathematically, If the variable $x$ is used to draw conclusions concerning the variable $y$.

$y$ is called dependent or response variable.
$x$ is called predictor, independent, or explanatory variable.

It is the least squares estimator of a linear regression model with a single explanatory variable. The regression line (known as the least squares line) is a plot of the expected value of the dependent variable for all values of the independent variable. Technically, it is the line that "minimizes the squared residuals". The regression line is the one that best fits the data on a scatterplot. If the relationship between two variables is linear is can be summarized by a straight line. A straight line can be described by an equation:

$$y = a + b x$$

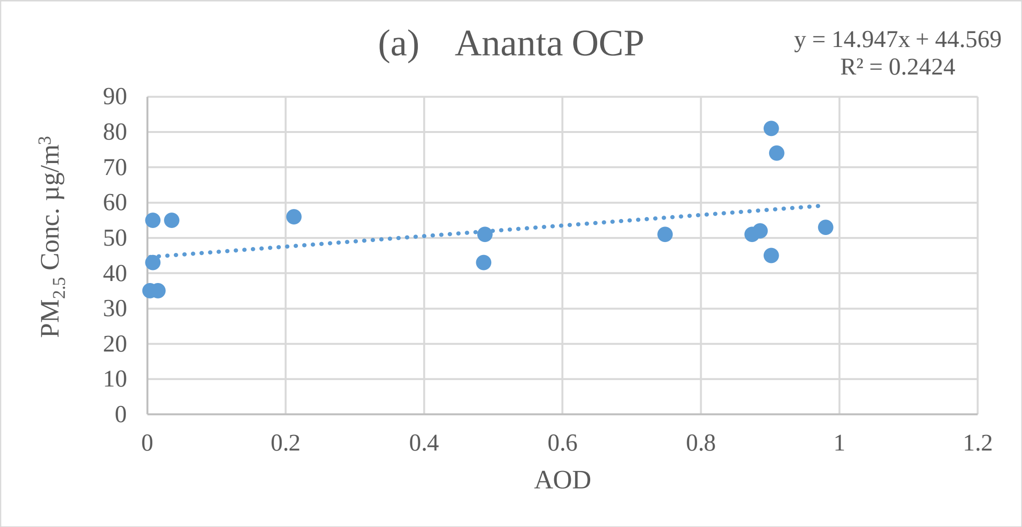
a is called the intercept and b the slope of the equation.

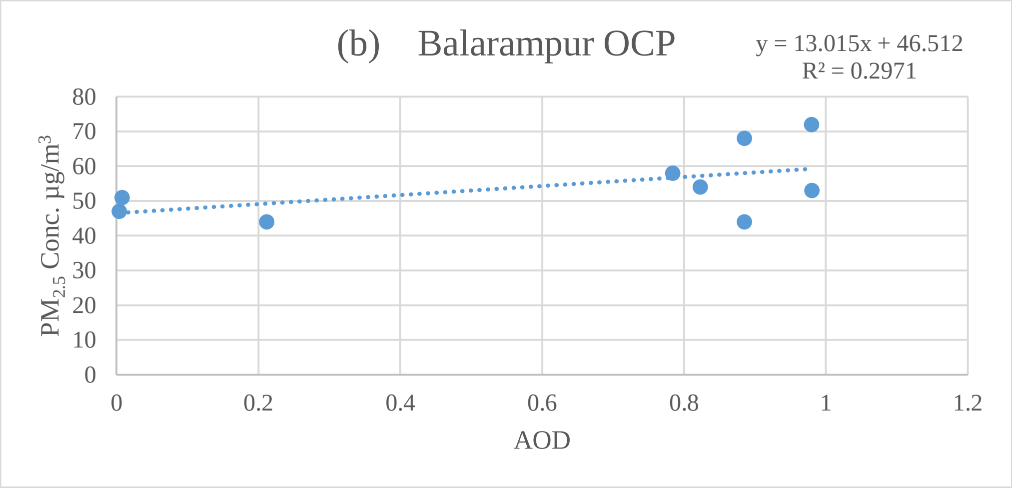
For prediction of PM from AOD value, particulate matter concentration ($PM_{2.5}$) data are taken as dependent variable and AOD data are taken as independent variable. The PM data collected from the coal mines area used. The descriptive statistics (mean, standard deviation and number of sample) are presented in the Table5 .1. Figure 5.1 (a-p) showed the simple linear regression analysis between $PM_{2.5}$ and MODIS AOD level at 550nm of different coalfields.

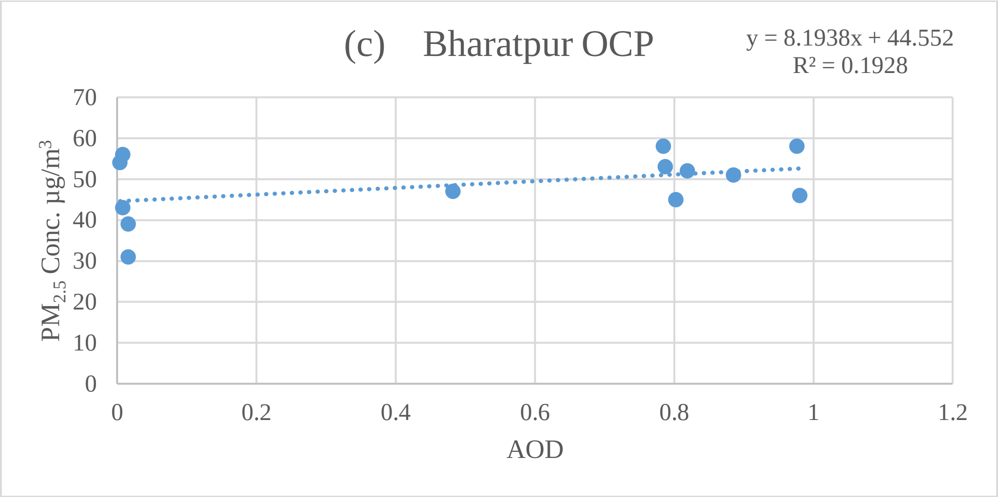
Table 5.1: Descriptive statistics of PM concentration and AOD level

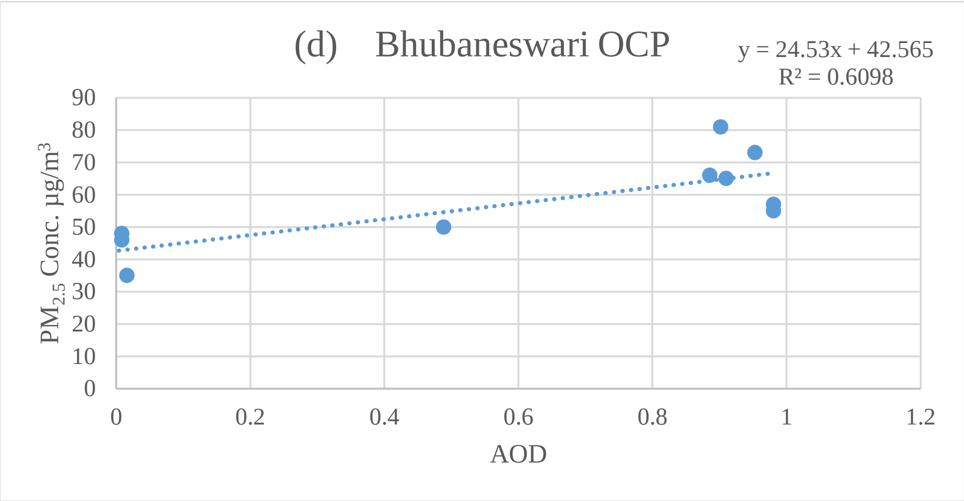
| Location | Statistical parameter | 24-hrs. avg. PM2.5 conc. (µg/m3) | Aqua AOD |
|---|---|---|---|
| Ananta OCP | Mean | 52 | 0.497 |
| | Std. Deviation | 12.398 | 0.408 |
| | Number of days | 15 | 15 |
| | | | |
| Balaram OCP | Mean | 54.556 | 0.618 |
| | Std. Deviation | 9.951 | 0.417 |
| | Number of days | 9.000 | 9.000 |
| | | | |
| Bharatpur OCP | Mean | 48.692 | 0.505 |
| | Std. Deviation | 7.920 | 0.424 |
| | Number of days | 13.000 | 13.000 |
| | | | |
| Bhubaneswari | Mean | 57.600 | .613 |
| | Std. Deviation | 13.794 | .439 |
| | Number of days | 10.000 | 10.000 |
| | | | |
| Chendipada OCP | Mean | 45.444 | 0.393 |
| | Std. Deviation | 5.790 | 0.377 |
| | Number of days | 9.000 | 9.000 |
| | | | |
| Kaniha OCP | Mean | 53.800 | 0.515 |
| | Std. Deviation | 8.390 | 0.361 |
| | Number of days | 10.000 | 10.000 |
| | | | |
| Lingaraj OCP | Mean | 49.778 | 0.455 |
| | Std. Deviation | 9.397 | 0.428 |
| | Number of days | 18.000 | 18.000 |
| | | | |
| Talcher coalaires | Mean | 44.500 | 0.480 |
| | Std. Deviation | 7.091 | 0.415 |

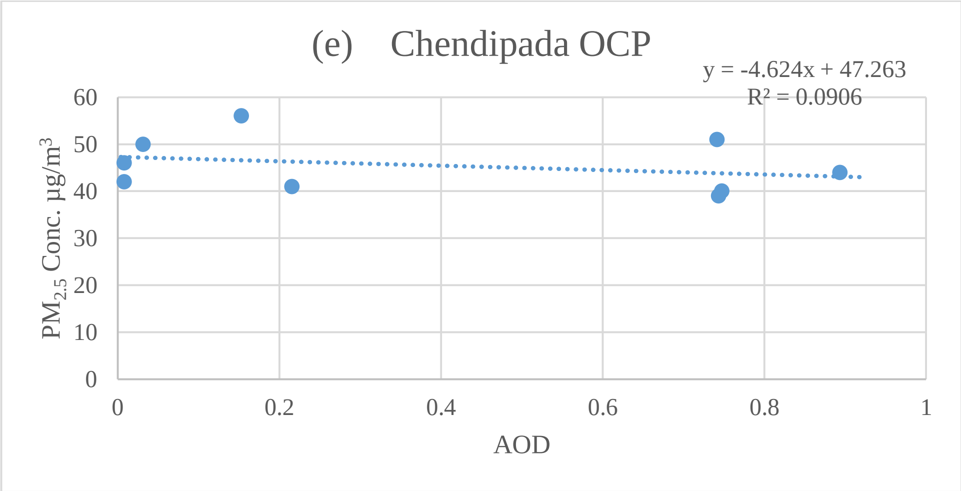
| | | | |
|---|---|---|---|
| | Number of days | 8.000 | 8.000 |
| | | | |
| Basundhara OCP | Mean | 47.778 | 0.217 |
| | Std. Deviation | 9.947 | 0.283 |
| | Number of days | 9.000 | 9.000 |
| | | | |
| Kulda OCP | Mean | 55.294 | 0.326 |
| | Std. Deviation | 13.963 | 0.316 |
| | Number of days | 17.000 | 17.000 |
| | | | |
| Belpahar OCP | Mean | 49.400 | 0.246 |
| | Std. Deviation | 10.772 | 0.340 |
| | Number of days | 10.000 | 10.000 |
| | | | |
| Lajkura OCP | Mean | 0.398 | 47.900 |
| | Std. Deviation | 0.288 | 12.360 |
| | Number of days | 10.000 | 10.000 |
| | | | |
| Liliary OCP | Mean | 50.500 | 0.494 |
| | Std. Deviation | 10.100 | 0.303 |
| | Number of days | 8.000 | 8.000 |
| | | | |
| Samaleswari OCP | Mean | 49.182 | 0.527 |
| | Std. Deviation | 14.240 | 0.350 |
| | Number of days | 11.000 | 11.000 |
| | | | |
| Orient area | Mean | 49.714 | 0.532 |
| | Std. Deviation | 12.252 | 0.265 |
| | Number of days | 21.000 | 21.000 |
| | | | |
| | Mean | 48.692 | 0.416 |
| Lakhanpur OCP | Std. Deviation | 15.713 | 0.344 |
| | Number of days | 13.000 | 13.000 |

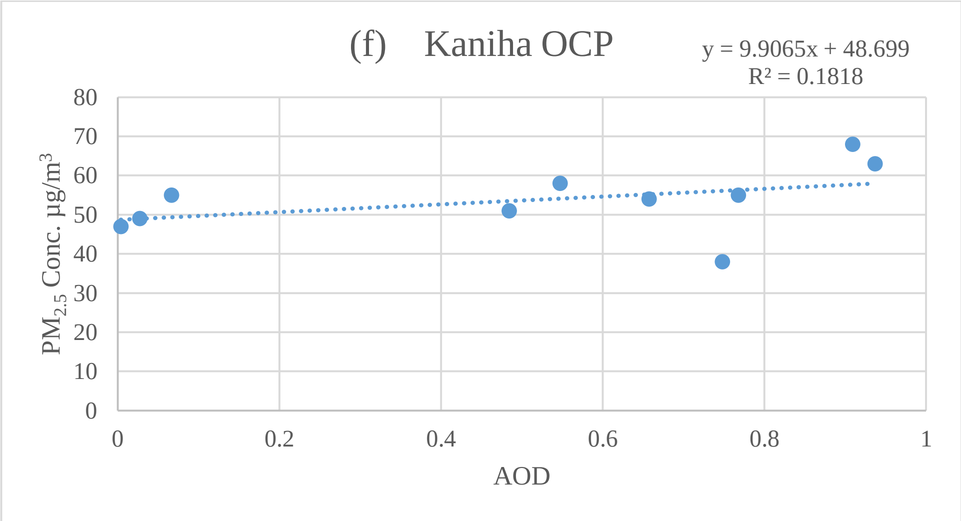

(a) Ananta OCP
y = 14.947x + 44.569
R² = 0.2424
PM2.5 Conc. µg/m3
AOD
90
80
70
60
50
40
30
20
10
0
0
0.2
0.4
0.6
0.8
1
1.2

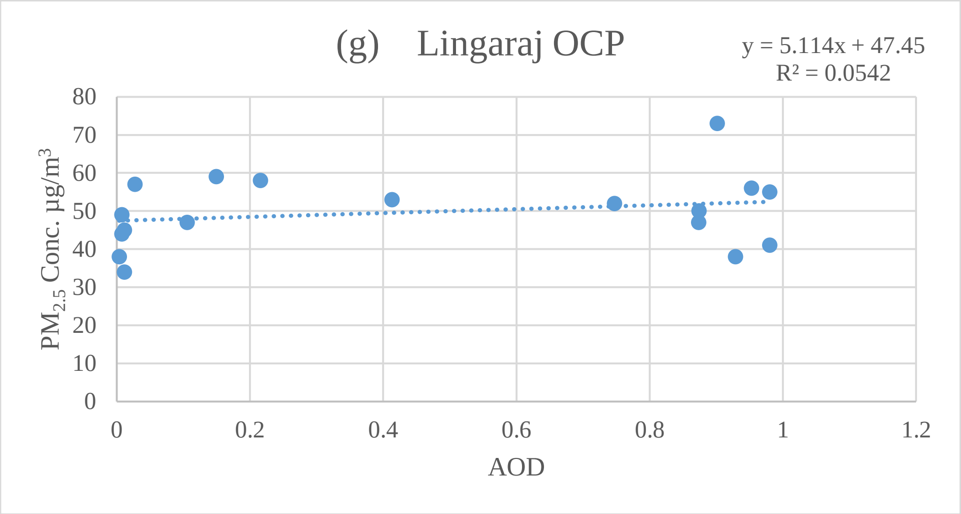

(b) Balarampur OCP
y = 13.015x + 46.512
R² = 0.2971
PM2.5 Conc. µg/m3
AOD
80
70
60
50
40
30
20
10
0
0
0.2
0.4
0.6
0.8
1
1.2

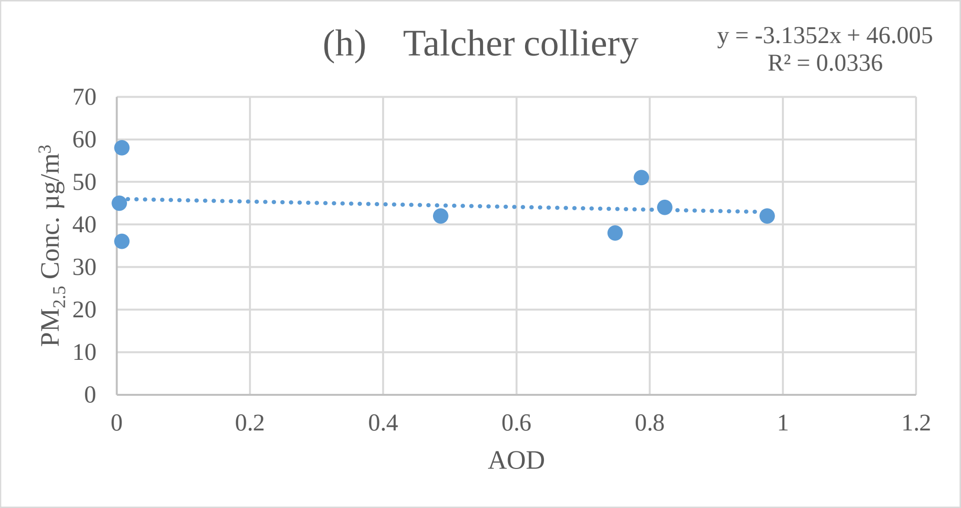

(c) Bharatpur OCP
y = 8.1938x + 44.552
R² = 0.1928
PM2.5 Conc. µg/m3
AOD
70
60
50
40
30
20
10
0
0
0.2
0.4
0.6
0.8
1
1.2

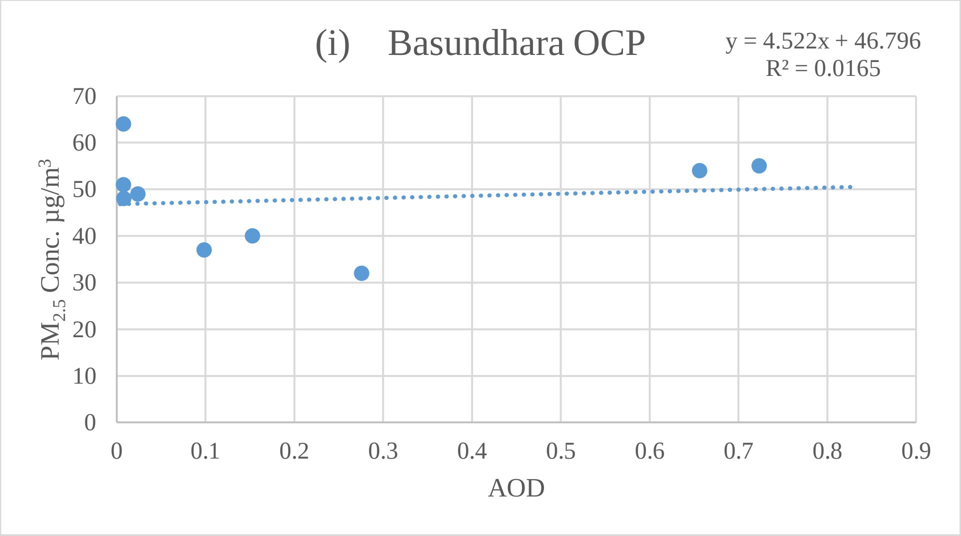

(d) Bhubaneswari OCP
y = 24.53x + 42.565
R² = 0.6098
90
80
70
60
50
40
30
20
10
0
PM2.5 Conc. µg/m3
0
0.2
0.4
0.6
0.8
1
1.2
AOD

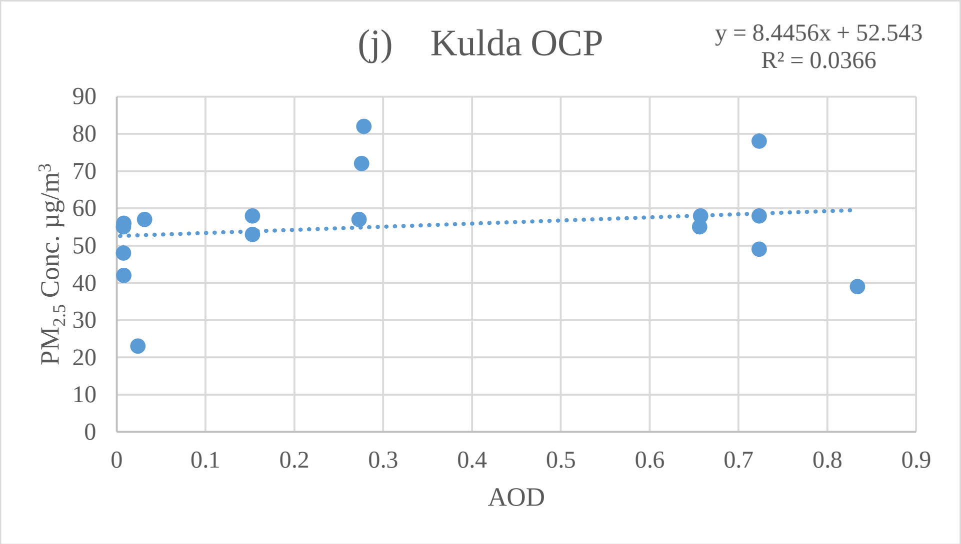

(e) Chendipada OCP
y = -4.624x + 47.263
R² = 0.0906
60
50
40
30
20
10
0
PM2.5 Conc. µg/m3
0
0.2
0.4
0.6
0.8
1
AOD

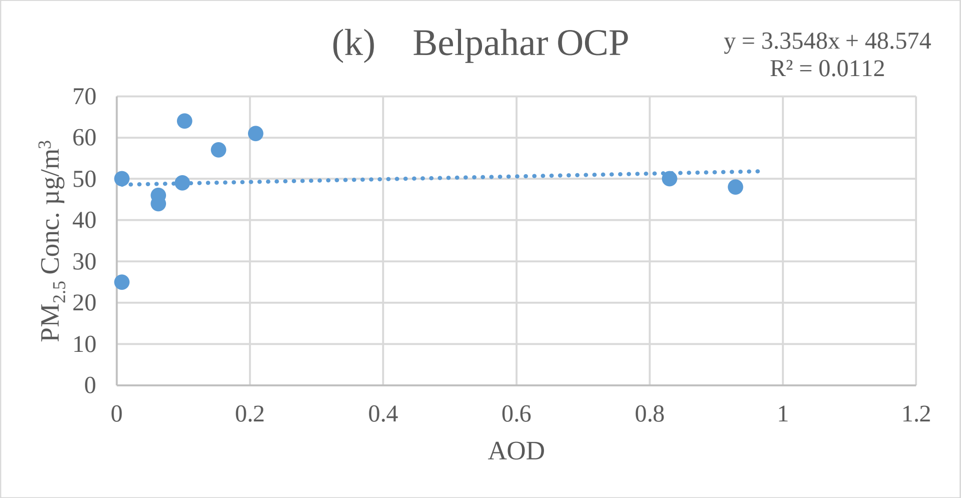

(f) Kaniha OCP
y = 9.9065x + 48.699
R² = 0.1818
80
70
60
50
40
30
20
10
0
PM2.5 Conc. µg/m3
0
0.2
0.4
0.6
0.8
1
AOD

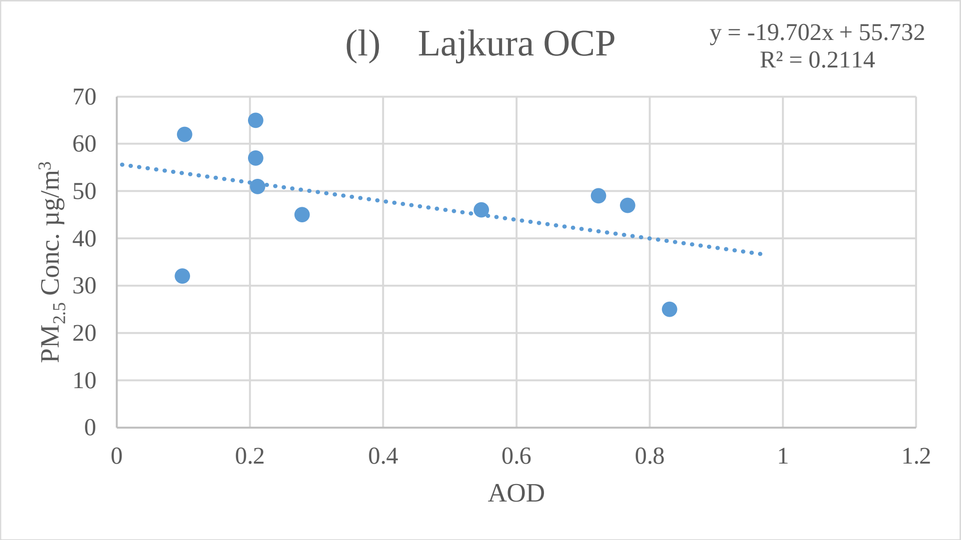

(g) Lingaraj OCP
y = 5.114x + 47.45
R² = 0.0542
PM2.5 Conc. µg/m3
AOD
0
10
20
30
40
50
60
70
80
0
0.2
0.4
0.6
0.8
1
1.2

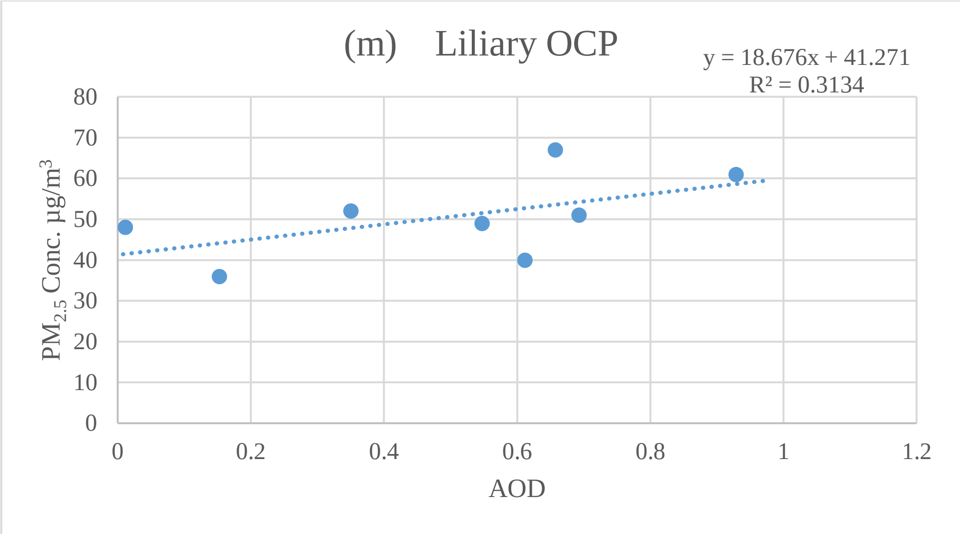

(h) Talcher colliery
y = -3.1352x + 46.005
R² = 0.0336
PM2.5 Conc. µg/m3
AOD
0
10
20
30
40
50
60
70
0
0.2
0.4
0.6
0.8
1
1.2

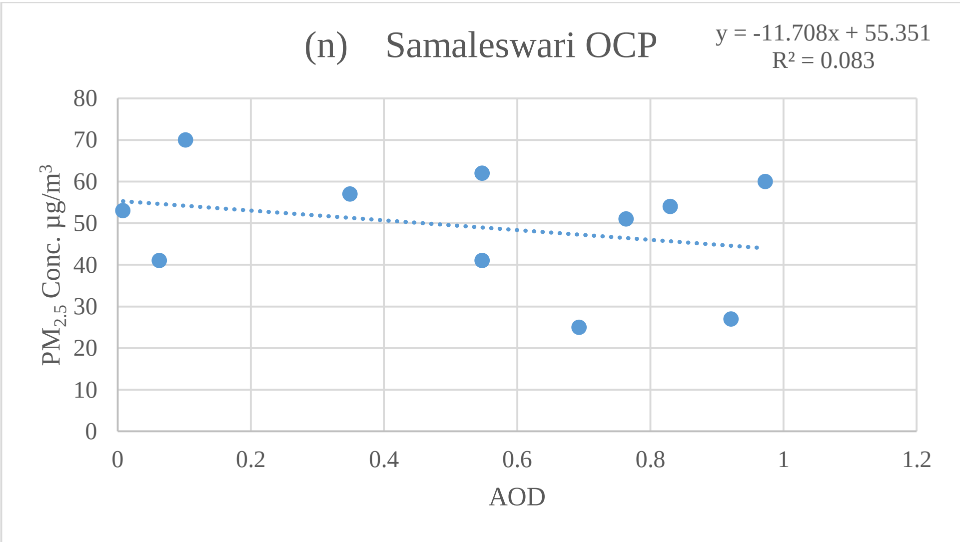

(i) Basundhara OCP
y = 4.522x + 46.796
R² = 0.0165
PM2.5 Conc. µg/m3
AOD
0
10
20
30
40
50
60
70
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9

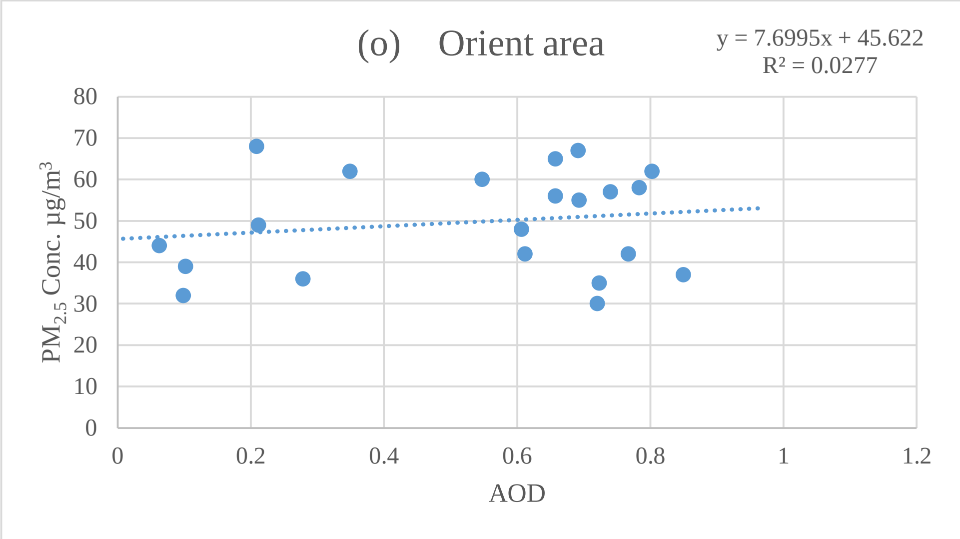

(j) Kulda OCP
y = 8.4456x + 52.543
R² = 0.0366
PM2.5 Conc. µg/m3
AOD
0
10
20
30
40
50
60
70
80
90
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9


(k) Belpahar OCP
y = 3.3548x + 48.574
R² = 0.0112
PM2.5 Conc. µg/m3
AOD
0
10
20
30
40
50
60
70
0
0.2
0.4
0.6
0.8
1
1.2


(l) Lajkura OCP
y = -19.702x + 55.732
R² = 0.2114
PM2.5 Conc. µg/m3
AOD
0
10
20
30
40
50
60
70
0
0.2
0.4
0.6
0.8
1
1.2


(m) Liliary OCP
y = 18.676x + 41.271
R² = 0.3134
PM2.5 Conc. µg/m3
AOD
80
70
60
50
40
30
20
10
0
0
0.2
0.4
0.6
0.8
1
1.2


(n) Samaleswari OCP
y = -11.708x + 55.351
R² = 0.083
PM2.5 Conc. µg/m3
AOD
80
70
60
50
40
30
20
10
0
0
0.2
0.4
0.6
0.8
1
1.2



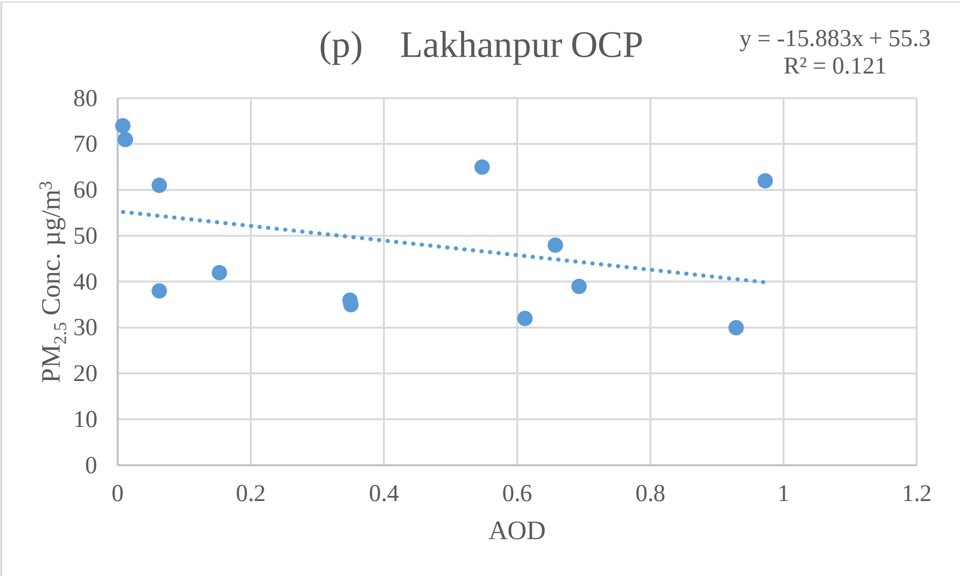




Figure 5.1: (a)-(p) Simple linear regression graphs

(a) Ananta OCP, (b) Balaram OCP, (c) Bharatpur OCP, (d) Bhubaneswari OCP, (e) Chendipada OCP, (f) Kaniha OCP, (g) Lingaraj OCP, (h) Talcher colliery, (i) Basundhara OCP, (j) Kulda OCP, (k) Belpahar OCP, (l) Lajkura OCP, (m) Liliary OCP, (n) Samaleswari OCP, (o) Orient area, (p) Lakhanpur OCP

The regression analysis of daily averaged $PM_{2.5}$ and MODIS AOD level explained about the fitness of the model. The simple regression analyses result indicated that the regression coefficient values were ranged from 0.01 (Basundhara OCP) to 0.6 (Bhubneswari OCP). Out of 16 locations, 5 were showed a negative correlation value. The negative values or weak regression coefficient indicate that some other factors influences the $PM_{2.5}$ concentrations in the regions. Thus, the simple regression model is not suitable for prediction of $PM_{2.5}$ concentration from AOD values. For this reason, multiple regression analyses were conducted for better understanding the influences of other factors (meteorological factors).

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### 5.2.2 Multiple regression analysis

Multiple linear regression model estimates the relationship between two or more explanatory variables and a dependent variable by fitting a linear equation to the data set. Every value of the independent variable x is associated with a value of the dependent variable y.

Mathematically,

$Y_i = B + B_1X_{i1} + B_2X_{i2} + \ldots\ldots\ldots\ldots\ldots + B_pX_{ip} + e_i$

For i = 1, 2……, n

In the least square model the best fitting line for the observed data is calculated by minimizing the sum of the squares of the vertical deviations from each point to the line.

In this study, five meteorological parameters (wind speed, solar radiation, precipitation, and relative humidity) were considered for the multiple regression analysis. The PM was taken as dependent variable and MODIS AOD data and the meteorological parameters (wind speed, solar radiation, precipitation, and relative humidity) were taken as the explanatory variable. The PM and AOD data used in the multivariable linear regression are the same data which were used in simple linear regression analysis. The meteorological data were collected for the corresponding days for each locations. Table 5.2 showed the descriptive statistics of diurnal variation of meteorological parameters.

The results of multivariable linear regression analyses were presented in the Table 5.3. It was found that there were significant improvement in the regression coefficient values in multiple regression model for all the locations. The $R^2$ value of Bhubaneswari OCP was improved to 0.96 from 0.6. The introduction of meteorological parameter has increased the prediction accuracy of PM concentration from AOD level. This also indicates that the PM monitoring stations were significantly influenced by the meteorological parameters.

Table 5.2: Descriptive statistics of diurnal variation of meteorological parameters.

| **Location** | **Statistical parameters** | **24 hr avg. temp** | **Precipitation (mm)** | **Wind Speed (m/s)** | **Relative humidity (fraction)** | **solar radiation (MJ/m2)** |
|---|---|---|---|---|---|---|
| Ananta OCP | Mean | 33.74 | 0.09 | 1.70 | 0.35 | 25.96 |
| | Std. Deviation | 2.92 | 0.26 | 0.40 | 0.09 | 2.31 |
| | Number of days | 15.00 | 15.00 | 15.00 | 15.00 | 15.00 |
| Balaram OCP | Mean | 32.57 | 1.97 | 1.82 | 0.37 | 23.73 |
| | Std. Deviation | 3.11 | 5.91 | 0.42 | 0.14 | 8.43 |
| | Number of days | 9.00 | 9.00 | 9.00 | 9.00 | 9.00 |
| Bharatpur OCP | Mean | 34.17 | 0.07 | 1.98 | 0.34 | 25.02 |
| | Std. Deviation | 2.68 | 0.17 | 0.51 | 0.09 | 3.21 |
| | Number of days | 13.00 | 13.00 | 13.00 | 13.00 | 13.00 |
| Bhubaneswari OCP | Mean | 32.99 | 0.05 | 1.71 | 0.32 | 25.02 |
| | Std. Deviation | 3.15 | 0.17 | 0.36 | 0.09 | 2.92 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Number of days | 10.00 | 10.00 | 10.00 | 10.00 | 10.00 |
| Chendipada OCP | Mean | 33.57 | 0.14 | 1.63 | 0.35 | 22.14 |
| | Std. Deviation | 2.24 | 0.28 | 0.33 | 0.13 | 4.86 |
| | Number of days | 9.00 | 9.00 | 9.00 | 9.00 | 9.00 |
| Kaniha OCP | Mean | 34.51 | 1.77 | 1.98 | 0.39 | 22.96 |
| | Std. Deviation | 3.26 | 5.61 | 0.51 | 0.14 | 7.89 |
| | Number of days | 10.00 | 10.00 | 10.00 | 10.00 | 10.00 |
| Lingaraj OCP | Mean | 33.44 | 0.08 | 1.68 | 0.36 | 23.86 |
| | Std. Deviation | 2.94 | 0.21 | 0.37 | 0.11 | 4.40 |
| | Number of days | 18.00 | 18.00 | 18.00 | 18.00 | 18.00 |
| Talcher coalaries | Mean | 33.65 | 0.00 | 1.85 | 0.36 | 26.88 |
| | Std. Deviation | 2.01 | 0.00 | 0.46 | 0.10 | 1.40 |
| | Number of days | 8.00 | 8.00 | 8.00 | 8.00 | 8.00 |
| Basundhara OCP | Mean | 32.10 | 1.55 | 1.94 | 0.30 | 23.31 |
| | Std. Deviation | 3.00 | 4.61 | 0.56 | 0.13 | 5.54 |
| | Number of days | 9.00 | 9.00 | 9.00 | 9.00 | 9.00 |
| Kulda OCP | Mean | 32.81 | 1.04 | 2.03 | 0.31 | 22.77 |
| | Std. Deviation | 3.17 | 3.42 | 0.48 | 0.11 | 5.14 |
| | Number of days | 17.00 | 17.00 | 17.00 | 17.00 | 17.00 |
| Belpahar OCP | Mean | 33.69 | 0.01 | 2.26 | 0.26 | 25.49 |
| | Std. Deviation | 3.28 | 0.04 | 0.80 | 0.07 | 2.44 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Number of days | 10.00 | 10.00 | 10.00 | 10.00 | 10.00 |
| Lajkura OCP | Mean | 33.63 | 0.01 | 2.13 | 0.23 | 26.17 |
| | Std. Deviation | 3.40 | 0.04 | 0.58 | 0.07 | 2.49 |
| | Number of days | 10.00 | 10.00 | 10.00 | 10.00 | 10.00 |
| Liliary OCP | Mean | 34.525 | 0.000 | 2.005 | 0.252 | 26.277 |
| | Std. Deviation | 3.548 | 0.001 | 0.820 | 0.069 | 1.609 |
| | Number of days | 8.000 | 8.000 | 8.000 | 8.000 | 8.000 |
| Samaleswari OCP | Mean | 34.00 | 0.02 | 1.80 | 0.27 | 23.84 |
| | Std. Deviation | 3.08 | 0.06 | 0.56 | 0.08 | 4.23 |
| | Number of days | 11.00 | 11.00 | 11.00 | 11.00 | 11.00 |
| Orient area | Mean | 33.68 | 0.00 | 2.00 | 0.27 | 25.18 |
| | Std. Deviation | 3.35 | 0.00 | 0.57 | 0.08 | 3.23 |
| | Number of days | 21.00 | 21.00 | 21.00 | 21.00 | 21.00 |
| Lakhanpur OCP | Mean | 34.59 | 0.02 | 2.10 | 0.27 | 25.42 |
| | Std. Deviation | 2.96 | 0.06 | 0.85 | 0.07 | 3.43 |
| | Number of days | 13.00 | 13.00 | 13.00 | 13.00 | 13.00 |

Table 5.3: Multivariable regression analysis result

| Location | No. of data | $R^2$ | Sig. F | statistical parameter | AOD | 24 Hr avg. temp. 0C | Precipitation (mm) | Wind speed (m/s) | R.H. (fraction) | Solar radiation (MJ/m2) |
|---|---|---|---|---|---|---|---|---|---|---|
| Ananta OCP | 15 | 0.646 | 0.121 | Coefficient | 11.760 | -1.961 | -2.746 | 12.661 | -47.431 | 1.694 |
| | | | | std error | 8.70 | 1.07 | 13.25 | 9.86 | 33.57 | 1.45 |
| | | | | P- Value | 0.21 | 0.10 | 0.84 | 0.24 | 0.20 | 0.28 |
| Balaram OCP | 9 | 0.985 | 0.045 | Coefficient | 26.75 | 2.17 | -2.26 | 7.32 | -173.80 | -5.08 |
| | | | | std error | 3.36 | 0.48 | 0.74 | 3.11 | 21.89 | 0.65 |
| | | | | P- Value | 0.02 | 0.05 | 0.09 | 0.14 | 0.02 | 0.02 |
| Bharatpur OCP | 13 | 0.64 | 0.25 | Coefficient | 5.12 | -1.36 | -18.95 | 7.64 | 4.35 | 1.08 |
| | | | | std error | 5.71 | 1.17 | 19.40 | 6.68 | 53.16 | 0.78 |
| | | | | P- Value | 0.40 | 0.29 | 0.37 | 0.30 | 0.94 | 0.22 |
| Bhubaneswari OCP | 10 | 0.966 | 0.026 | Coefficient | 18.83 | -2.59 | -10.99 | 5.86 | 3.71 | 1.20 |
| | | | | std error | 61.21 | 0.94 | 21.68 | 25.11 | 77.37 | 5.76 |
| | | | | P- Value | 0.78 | 0.07 | 0.65 | 0.83 | 0.96 | 0.85 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Chendipada OCP | 9 | 0.969 | 0.091 | Coefficient | 4.92 | 2.25 | 0.11 | -17.98 | 15.24 | -0.46 |
| | | | | std error | 3.05 | 0.46 | 3.69 | 4.55 | 9.72 | 0.39 |
| | | | | P- Value | 0.25 | 0.04 | 0.98 | 0.06 | 0.26 | 0.36 |
| Kaniha OCP | 10 | 0.667 | 0.545 | Coefficient | 14.97 | 0.70 | 3.02 | 7.93 | -90.71 | 0.68 |
| | | | | std error | 16.34 | 2.58 | 3.43 | 18.04 | 59.09 | 2.16 |
| | | | | P- Value | 0.43 | 0.80 | 0.44 | 0.69 | 0.22 | 0.77 |
| Lingaraj OCP | 18 | 0.223 | 0.778 | Coefficient | -2.99 | 0.58 | -19.17 | 9.86 | -79.51 | -0.74 |
| | | | | std error | 9.20 | 1.04 | 16.79 | 11.26 | 54.36 | 0.96 |
| | | | | P- Value | 0.75 | 0.59 | 0.28 | 0.40 | 0.17 | 0.46 |
| Talcher | 8 | 0.959 | 0.368 | Coefficient | -4.87 | -6.76 | 8773.23 | 5.07 | 125.55 | -8.38 |
| | | | | std error | 13.15 | 2.64 | 2569.89 | 5.29 | 36.13 | 4.65 |
| | | | | P- Value | 0.77 | 0.24 | 0.18 | 0.51 | 0.18 | 0.32 |
| Basundhara OCP | 9 | 0.68 | 0.686 | Coefficient | -9.46 | 1.53 | -1.88 | 15.75 | -2.49 | -1.64 |
| | | | | std error | 25.65 | 2.61 | 2.02 | 12.11 | 80.80 | 1.78 |
| | | | | P- Value | 0.75 | 0.62 | 0.45 | 0.32 | 0.98 | 0.45 |
| Kulda OCP | 17 | 0.349 | 0.534 | Coefficient | 20.25 | -0.74 | 0.26 | -19.05 | 6.72 | -0.61 |
| | | | | std error | 13.78 | 1.23 | 1.82 | 9.06 | 58.28 | 1.01 |
| | | | | P- Value | 0.17 | 0.56 | 0.89 | 0.06 | 0.91 | 0.56 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Belpahar | 10 | 0.31 | 0.943 | Coefficient | 4.31 | 0.28 | 73.98 | 1.27 | -41.03 | -1.16 |
| | | | | std error | 19.94 | 2.81 | 191.63 | 9.96 | 84.85 | 2.83 |
| | | | | P- Value | 0.84 | 0.93 | 0.73 | 0.91 | 0.66 | 0.71 |
| Lajkura OCP | 10 | 0.936 | 0.066 | Coefficient | -0.01 | -0.12 | 6.62 | 0.45 | 5.21 | 0.30 |
| | | | | std error | 0.01 | 0.05 | 2.97 | 0.12 | 3.72 | 0.11 |
| | | | | P- Value | 0.13 | 0.08 | 0.11 | 0.03 | 0.26 | 0.07 |
| Liliary OCP | 8 | 0.99 | 0.043 | Coefficient | 30.96 | -0.94 | -4115.65 | -1.42 | -87.41 | 2.84 |
| | | | | std error | 1.71 | 0.09 | 238.06 | 0.52 | 4.65 | 0.20 |
| | | | | P- Value | 0.04 | 0.06 | 0.04 | 0.22 | 0.03 | 0.05 |
| Samaleswari OCP | 11 | 0.603 | 0.519 | Coefficient | -19.85 | -0.71 | 172.18 | 5.00 | -89.82 | 0.14 |
| | | | | std error | 15.23 | 2.33 | 118.16 | 21.20 | 114.91 | 2.12 |
| | | | | P- Value | 0.26 | 0.78 | 0.22 | 0.82 | 0.48 | 0.95 |
| Orient area | 21 | 0.271 | 0.541 | Coefficient | 11.78 | 1.27 | -3112.48 | -4.93 | 38.23 | -1.07 |
| | | | | std error | 11.29 | 0.91 | 3239.08 | 5.24 | 35.96 | 1.01 |
| | | | | P- Value | 0.31 | 0.18 | 0.35 | 0.36 | 0.31 | 0.31 |
| Lakhanpur OCP | 13 | 0.519 | 0.464 | Coefficient | -39.98 | 0.94 | 188.01 | -10.52 | -42.03 | -0.05 |
| | | | | std error | 19.25 | 1.77 | 168.14 | 7.36 | 84.66 | 2.51 |
| | | | | P- Value | 0.08 | 0.61 | 0.31 | 0.20 | 0.64 | 0.98 |

# Chapter 6

# Conclusions

In India, the rate of energy demand increases rapidly. The energy production in India mainly depends on the coal. This leads to increase in coal production. But the coal mining industries are considered as major air pollution sources. Most of the coal mining activities have polluted the quality of air significantly. It is well established that longterm exposure to high concentration of air pollutants leads to many health diseases. Thus, proper monitoring of air pollution is required to prevent the emission from the significant sources. The traditional ground level monitoring of PM concentration are time consuming and expensive. It is also difficult to establish the monitoring station in all locations. So in this study, satellite data were used for the estimation of PM concentration. The Moderate Resolution Imaging Spectroradiometer (MODIS) satellite data were used for estimating the Aerosol Optical Depth (AOD) levels over mining region. These AOD data along with the meteorological data were further used for prediction of $PM_{2.5}$ concentrations in the mining regions. Simple and multiple linear regression analyses were conducted to predict the $PM_{2.5}$ concentration from the AOD level. The result showed that prediction of particulate matter concentration through the simple linear regression analysis was not satisfactory. In multiple regression model, the results were significantly improved while meteorological parameters were used. The models were also statistically significant except in some cases. Thus, prediction of PM from multiple regression analysis is suitable.

**Future scope**

The future scope of the research is to develop a model with more number of data for its reliability and to identify more number of factors that influence the $PM_{2.5}$ concentrations in the mining regions.

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# Index